THE PHILIPPINE
JOURNAL OF SCIENCE

171114

THE PHILIPPINE JOURNAL OF SCIENCE

CORROSION OF IRON IN SULPHURIC ACID. EFFECT OF CHROMIUM COMPOUNDS [1]

By George W. Heise and Amando Clemente

Of the Bureau of Science, Manila

ONE TEXT FIGURE

The use of passivifying agents in inhibiting the corrosion of iron is, of course, well known. Thus, the addition of potassium dichromate to water has been suggested as a means of preventing boiler corrosion. [2]

Under certain conditions, however, substances that ordinarily passivify may increase the rate of corrosion. For example, the rate of corrosion of iron in a salt solution is accelerated by the addition of potassium dichromate because, according to Friend, [3] a reaction occurs whereby free acid is formed, as follows:

$$H_2O + K_2Cr_2O_7 + 2NaCl \rightleftarrows K_2CrO_4 + Na_2CrO_4 + 2HCl.$$

In the presence of free acid, potassium dichromate acts as a depolarizer, removing hydrogen, and thus facilitates the dissolution of the iron. The accelerated corrosion of iron in sulphuric acid in the presence of potassium chromate and dichromate was determined experimentally by Watts [4] who reported as follows:

The great increase in corrosion caused by the addition of potassium chromate was therefore rather surprising. A comparison * * * sug-

[1] Received for publication, February 27, 1918.
[2] Cushman, A. S., Bull. U. S. Dept. Agr. 30 (1907).
[3] Friend, J. N., Journ. Iron and Steel Inst. 2 (1908) 9, quoted by Friend, J. N., Corrosion of Iron and Steel. Longmans, Green & Co. (1911) 163.
[4] Watts, O. P., The effect of various substances on the rate of corrosion of iron by sulphuric acid, Trans. Am. Electrochem. Soc. 21 (1912) 337–353.

gests that the protective action heretofore ascribed to chromates may really be due solely to the chromium which they contain, and not to the chromate as such.

The stimulative action of potassium chromate and dichromate is in striking contrast to the protection afforded by chromium sulphate. Chromealum is a much less efficient protective agent per unit of chromium than chromium sulphate. These experiments indicate the possibility of a revision in our ideas of the manner in which chromates protect iron from rusting, and may lead to the substitution of chromium salts for the chromates heretofore used to render iron "passive."

Among the data accumulated by us, in the course of an extensive series of corrosion tests, are results which have direct bearing on the question of the effect of the addition of chromium compounds on the corrosion of iron in sulphuric acid. Since there seems to be no good prospect for the completion of this series as originally planned, these rather fragmentary results are offered at this time, as of possible interest.

The series of experiments to be described shows the effect on the corrosion of iron in sulphuric acid, (1) of varying concentration of sulphuric acid and of potassium dichromate, and (2) of additions of chromium salts.

EXPERIMENTAL

The iron used was a sample of very pure commercial sheet iron, over 99.8 per cent pure, but containing a very small amount of copper. It was cut into strips 10 centimeters long and 2.5 centimeters wide, cleaned of mill scale by being made the cathode in a bath of sulphuric acid,[5] dipped in a weak caustic alkali solution, scrubbed, rinsed, dried, and kept packed in lime until wanted.

The corrosion tests were made in half-liter, wide-mouthed, glass bottles, covered with watch glasses. The sulphuric acid used was chemically pure and free from arsenic, 400 cubic centimeter portions of solution being used in each test. All tests were performed in a large water bath (covered to avoid any disturbing factor due to light) in which the temperature was maintained at $28° \pm 1.0°$ C.

The following data were obtained:

[5] Reed, C. J., Trans. Am. Electrochem. Soc. 11 (1907) 181.

—Effect of addition of potassium dichromate on the corrosion of iron in 0.5 N sulphuric acid.

Experiment No.	Potassium dichromate added.	Weight of iron.	Loss due to corrosion in 20 hours.
	Grams per liter.	*Grams.*	*Grams.*
	0.0	15.055	0.070
	0.0	15.884	0.073
	2.5	14.231	0.517
	2.5	14.176	0.474
	6.25	15.410	1.163
	6.25	15.301	1.125
	12.5	13.985	2.071
	12.5	15.756	2.109
	18.75	15.007	1.775
	18.75	13.948	1.726
	25.0	15.457	0.002
	25.0	15.462	0.002
	37.5	15.774	0.001
	37.5	15.101	-0.003

orrosion of iron in 0.5 *N* sulphuric acid became pro-
ly greater with increasing additions of potassium di-
e, until a maximum was reached. Further additions
sium dichromate decreased the amount of corrosion, the
oming passive when between 18.75 and 25 grams of
m dichromate were present in a liter of 0.5 *N* sulphuric

similar results are obtained with normal sulphuric acid
n by the data in Tables 2 and 3.

—Effect of addition of potassium dichromate on the corrosion of iron in normal sulphuric acid.

Experiment No.	Potassium dichromate added.	Weight of iron.	Loss due to corrosion in 21 hours.
	Grams per liter.	*Grams.*	*Grams.*
	0.0	14.624	0.156
	2.5	15.597	0.587
	2.5	14.953	0.563
	12.5	15.768	2.219
	12.5	15.216	2.225
	25.0	15.489	4.166
	25.0	14.122	4.129
	50.0	15.109	3.334
	50.0	15.424	3.836
	75.0	14.578	0.000
	75.0	14.999	0.000

TABLE 1.—*Effect of addition of potassium dichromate on the corrosion of iron in 0.5 N sulphuric acid.*

Experiment No.	Potassium dichromate added.	Weight of iron.	Loss due to corrosion in 20 hours.
	Grams per liter.	*Grams.*	*Grams.*
1	0.0	15.065	0.070
2	0.0	15.884	0.073
3	2.5	14.231	0.517
4	2.5	14.176	0.474
5	6.25	15.410	1.163
6	6.25	15.301	1.125
7	12.5	13.985	2.071
8	12.5	15.756	2.109
9	18.75	15.007	1.775
10	18.75	13.948	1.726
11	25.0	15.457	0.002
12	25.0	15.462	0.002
13	37.5	15.774	0.001
14	37.5	15.101	-0.003

The corrosion of iron in 0.5 N sulphuric acid became progressively greater with increasing additions of potassium dichromate, until a maximum was reached. Further additions of potassium dichromate decreased the amount of corrosion, the iron becoming passive when between 18.75 and 25 grams of potassium dichromate were present in a liter of 0.5 N sulphuric acid.

Very similar results are obtained with normal sulphuric acid as shown by the data in Tables 2 and 3.

TABLE 2.—*Effect of addition of potassium dichromate on the corrosion of iron in normal sulphuric acid.*

Experiment No.	Potassium dichromate added.	Weight of iron.	Loss due to corrosion in 21 hours.
	Grams per liter.	*Grams.*	*Grams.*
15	0.0	14.624	0.156
16	2.5	15.597	0.587
17	2.5	14.953	0.563
18	12.5	15.768	2.219
19	12.5	15.216	2.225
20	25.0	15.489	4.166
21	25.0	14.122	4.129
22	50.0	15.109	3.334
23	50.0	15.424	3.336
24	75.0	14.578	0.000
25	75.0	14.999	0.000

As in the experiments recorded with 0.5 N acid, the corrosion of iron with increasing potassium dichromate concentration in normal sulphuric acid first increased, then decreased, and finally was entirely inhibited. A much greater salt concentration was necessary, however, to effect passivity than was required in the case of the more dilute acid. These first experiments indicated a maximum corrosion rate with a concentration between 25 and 50 grams of salt per liter, and passivity beyond 50 grams of potassium dichromate per liter of acid. To locate these points more closely, the experiments explained in Table 3 were performed.

TABLE 3.—*Effect of addition of potassium dichromate on the corrosion of iron in normal sulphuric acid.*

Experiment No.	Potassium dichromate added.	Weight of iron.	Loss after 24 hours.
	Grams per liter.	*Grams.*	*Grams.*
26	0	14.841	0.143
27	0	14.755	0.125
28	30	16.119	4.331
29	30	15.031	4.278
30	35	14.692	3.715
31	35	15.526	3.820
32	40	15.217	3.659
33	40	15.770	3.695
34	45	13.883	3.633
35	45	13.798	3.528
36	50	15.040	0.002
37	50	15.323	3.429
38	55	14.577	0.005
39	55	15.201	3.453
40	60	15.486	3.517
41	60	15.108	3.432
42	65	15.306	3.281
43	65	14.638	0.003
44	70	15.405	0.003
45	70	15.239	0.002

As in the preceding experiments, increasing quantities of potassium dichromate decreased the amount of corrosion. With additions above 45 grams of salt per liter results became exceedingly irregular, and no definite passivifying concentration was determined, though passivity was effected in individual cases for concentrations as low as 50 grams of salt per liter.

With 2 N sulphuric acid, the addition of potassium dichromate induced no passivity, as shown in Table 4, even when the acid solution was saturated with the salt.

TABLE 4.—*Effect of addition of potassium dichromate on the corrosion of iron in 2 N sulphuric acid.*

Experiment No.	Potassium dichromate added.	Weight of iron.	Loss due to corrosion in 21 hours.
	Grams per liter.	*Grams.*	*Grams.*
46	0	15.685	0.201
47	25	14.974	4.814
48	25	14.998	4.408
49	50	15.424	6.802
50	50	15.295	6.727
51	75	15.510	6.808
52	75	14.633	6.231
53	100	15.240	6.683
54	100	15.871	6.809

The amount of potassium dichromate added (40 grams) was more than would dissolve in 400 cubic centimeters of 2 *N* acid, indicating that iron could not be passivified in acid saturated with potassium dichromate. With additions of more than 20 grams of the salt, the rate of corrosion no longer increased, which would seem to show that, but for the limited solubility of potassium dichromate, passivity might have been effected even in 2 *N* acid.

Table 5 shows the progressive corrosion of iron in sulphuric acid containing potassium chromate and potassium dichromate.

TABLE 5.—*Corrosion of iron in 10 per cent sulphuric acid. Effect of potassium chromate and potassium dichromate.*

Experiment No.	Addition.	Weight of iron.	Loss after—				Total loss in 169 hours.
			19 hours.	29 hours.	48 hours.	78 hours.	
		Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
55	None	15.399	0.163	0.204	0.177	0.170	0.714
56	do	15.762	0.142	0.141	0.159	0.160	0.602
57	Potassium chromate (K_2CrO_4) 2.5 g	15.296	0.887	0.265	0.162	0.186	1.000
58	do	18.455	0.611	0.218	0.133	0.192	1.154
59	Potassium dichromate ($K_2Cr_2O_7$) 2.5 g	15.807	0.545	0.268	0.146	0.185	1.144
60	do	18.211	0.579	0.226	0.167	0.262	1.234

The foregoing data show that both chromate and dichromate first accelerate corrosion; but that, after reduction to chromium salt has once taken place, the rate of corrosion is very similar to that taking place in acid alone, indicating that chromium

salts have little or no effect.   This conclusion was corroborated by the experiments recorded in Table 6.

TABLE 6.—*Corrosion of iron in normal sulphuric acid.   Effect of addition of chromium compounds.*

[Addition equivalent to 2.5 grams metal per liter of solution.]

Experiment No.	Addition.	Weight of iron.	Loss after—		Total loss in 49 hours.
			24 hours.	+25 hours.	
		Grams.	Grams.	Grams.	Grams.
61	None	15.914	0.173	0.189	0.362
62	Chromium sulphate a.	15.972	0.230	0.201	0.431
63	....do	15.574	0.176	0.191	0.367
64	Chromium chloride..	14.605	0.266	0.266	0.532
65	....do	14.563	0.365	0.312	0.677

a Added as chromic hydroxide.

Chromium chloride showed some acceleratory effect, but this was very slight as compared with the effects noted with chromates or dichromates.

DISCUSSION OF RESULTS

. The amount of potassium dichromate necessary to passivify iron became progressively greater as the sulphuric acid concentration increased.   In half-normal sulphuric acid, iron became passive with a potassium dichromate concentration above 19 grams per liter; in normal acid the critical concentration of potassium dichromate was above 50 grams; in twice-normal acid iron did not assume the passive state.

With increasing potassium dichromate concentrations, the corrosion in half-normal and in normal acid first increased and then gradually decreased.   In twice-normal acid the corrosion rose to a maximum as in less concentrated acid, but showed no decrease.

The corrosion data in Tables 1, 2, and 4 are shown graphically in fig. 1.   They indicate that, below the concentration which effects maximum corrosion, the amount of corrosion is proportional to the potassium dichromate concentration.

The marked inhibition of the corrosion of iron by chromium salts, recorded by Watts,[6] was not confirmed with the sample of iron used in the present investigation.   This discrepancy may,

6 Loc. cit.

Potassium dichromate concentration grams of $K_2 Cr_2 O_7$ in 400 cc. $H_2 SO_4$.
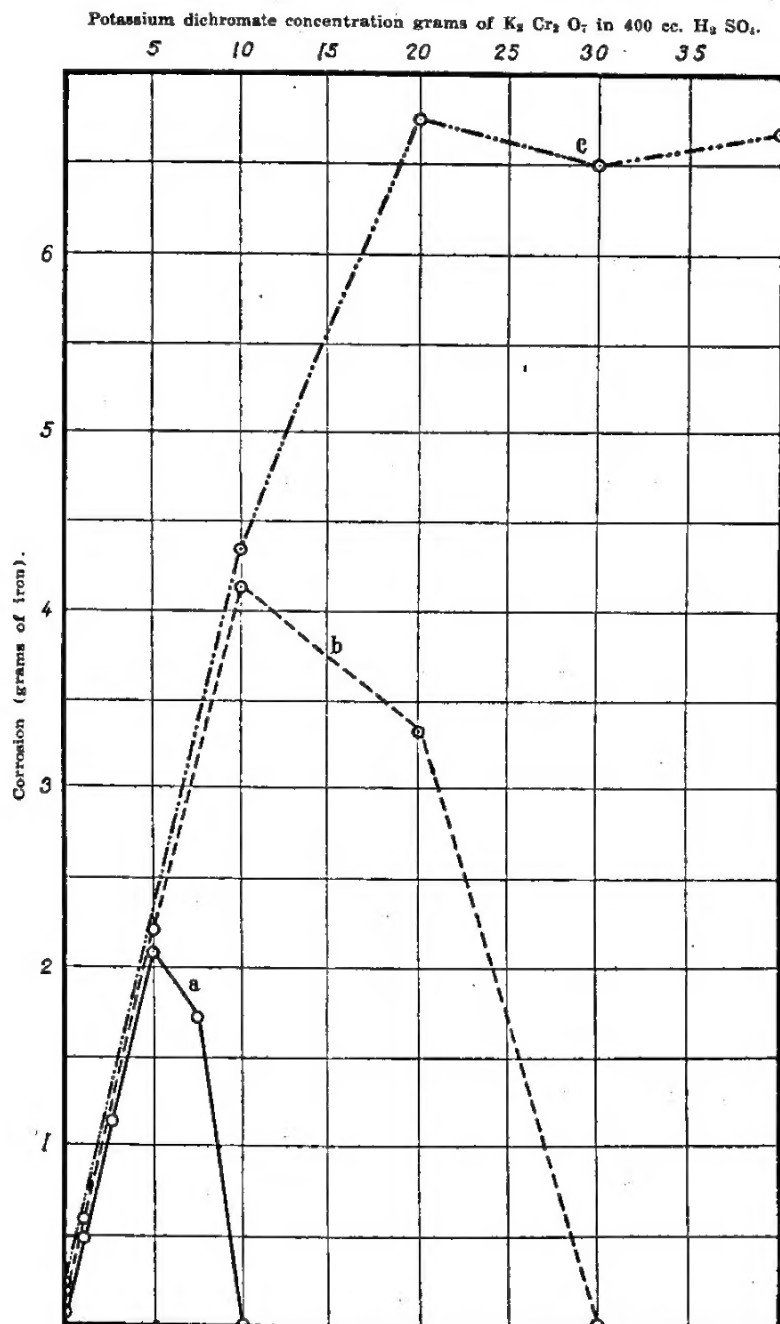

FIG. 1. The effect of potassium dichromate on corrosion of iron in sulphuric acid. Line *a*, 0.5 *N* sulphuric acid, 20 hours; line *b*, *N* sulphuric acid, 21 hours; line *c*, 2 *N* sulphuric acid, 22 hours.

however, be due to differences in the iron used and in the acid concentration employed. Though the effect of an alloyed metal on the corrosion of iron in acid may be markedly different than the effect of the same metal added to the acid in the form of a salt,[1] it may be of interest to point out that Monnartz[2] found that the addition of chromium to iron increased, if anything, the solubility of the resulting alloy in hydrochloric or sulphuric acid, conclusions which are in good agreement with our results.

This work has furnished no evidence to show that the passivifying effect of chromates or dichromates on iron is due to their chromium content.

[1] Burgess, C. F., and Aston, J., Influence of various elements on the corrodibility of iron, Journ. Ind. Eng. Chem. 5 (1913) 458–462.

[2] Monnartz, P., The study of the Fe-Cr alloys with particular regard to their solubility toward acids, Metallurgie 8 (1911) 161, 193; Chem. Abst. 5 (1911) 3035.

ILLUSTRATION

ON THE IDENTITY OF AEGIPHILA VIBURNIFOLIA
JUSSIEU

By E. D. MERRILL

Director and Botanist, Bureau of Science

ONE PLATE

In 1806 Jussieu[1] described as new a supposedly Philippine species which he called *Aegiphila viburnifolia*, the genus appertaining to the Verbenaceae, and all its species being confined to tropical America. No attempt seems to have been made to determine the identity of the species until 1911, when at my request the late Dr. C. B. Robinson, in passing through Paris, looked up Jussieu's type and supplied me with a few notes regarding it and also a photograph of it. Both he and Dr. Gagnepain failed to recognize the genus to which it really belonged, although both agreed that it appertained to the Celastraceae. From a not very critical examination of the photograph in 1914, I determined Jussieu's species as being the same as the Philippine one described in 1908 as *Euonymus philippinensis* Merr. & Rolfe, and erroneously adopted the binomial *Euonymus viburnifolius* Merr. for the Philippine form. A reëxamination of the photograph, the description, and Dr. Robinson's notes shows clearly that this disposition of Jussieu's species is erroneous, but that it is clearly the Malayan form described by King in 1896 as *Elaeodendron subrotundum*. An adjustment of the synonymy follows:

ELAEODENDRON VIBURNIFOLIUM (Juss.) comb. nov. Plate 1.

    Aegiphila viburnifolia Juss. in Ann. Mus. Paris 7 (1806) 76; Walp.
        Repert. 4 (1844–48) 124; Schauer in DC. Prodr. 11 (1847) 655.
    Elaeodendron subrotundum King in Journ. As. Soc. Beng. 65[2] (1896)
        356; Merr. in Journ. Str. Branch Roy. As. Soc. 76 (1917) 93.

I have examined the following material representing the species: "Philippines," *Sonnerat*, photograph of the type ex Herb. Jussieu. Malay Peninsula, Selangor, *Burkill 1248;* Johore, *Ridley 12481.* Singapore, *Baker 5850.* Borneo, Sarawak, *Foxworthy 119;* British North Borneo, *Foxworthy 623.*

[1] Ann. Mus. Paris 7 (1806) 76.

The species is not represented in our Philippine collections, and the type may not have come from the Archipelago. It is indicated on the original label as "Philippines herb. D. Commerson sans nom," and on a second label "Philippines. Plantes récoltées par Sonnerat et données a Commerson." Sonnerat on his voyage to India and China [2] stopped at Malacca, a locality within the known range of *Elaeodendron viburnifolium,* and he may have collected the specimen there. Or again he may well have collected it in the Philippines at Jolo (Yolo) [3] on his first voyage, where he stopped for a short time after leaving Zamboanga (Sambouangue). The Sulu Archipelago, including Jolo, has been very slightly explored from a botanical standpoint, and a species growing in or near the mangrove swamps on the east coast of Borneo is certainly to be expected in similar habitats in Sulu Archipelago. Whether or not the type was really from the Philippines, *Aegiphila viburnifolia* Juss. is clearly identical with *Elaeodendron subrotundum* King, and Jussieu's specific name should be adopted for the species.

For the common Philippine form to which I erroneously applied the binomial *Euonymus viburnifolius* [4] another name is necessary, and I can now see no reason why *Euonymus cochinchinensis* Pierre should not be adopted, as I can detect no constant differential differences between it and *E. philippinensis* Merr. & Rolfe. The synonymy will then be as follows:

EUONYMUS COCHINCHINENSIS Pierre Fl. Forest. Cochinch. 4 (1894) *t. 309*; Pitard in Lécomte Fl. Gén. Indo-Chine 1 (1912) 873, *fig. 108.*

Euonymus timorensis Turcz. in Bull. Soc. Nat. Mosc. 31 [1] (1858) 447; F.-Vill. Novis. App. (1880) 46; Vidal Phan. Cuming. Philip. (1885) 103, non Zipp.

Euonymus philippinensis Merr. & Rolfe in Philip. Journ. Sci. 3 (1908) Bot. 238.

Indochina, *Thorel 2080!, Harmand, Godefroy!, Pierre!* (all det. Pitard). Siam, *Annandale 1585!, 1829!.* Malay Peninsula, Pahang, *Burn-Murdoch!* (all det. as *E. javanicus* Blume). I refer the following Philippine material here: LUZON, Cagayan Province, *Adduru 68, 179:* Ilocos Norte Province, *Bur. Sci. 33209 Ramos:* Benguet Subprovince, *Elmer 6462, Bur. Sci. 3551 Mearns, Williams 1024:* Pangasinan Province, *For. Bur. 21677 Domingo, For. Bur. 19452 Agama:* Nueva Ecija Province, *Bur.*

[2] Sonnerat, P., Voyage aux Indes Orientales et a la Chine 2 (1782) 99–103.

[3] Sonnerat, P., Voyage a la Nouvelle Guinée (1776) 136.

[4] Philip. Journ. Sci. 9 (1914) Bot. 312.

Sci. 26322 Ramos & Edaño: Rizal Province, *Merrill Phil. Pl. 1078, Bur. Sci. 4612, 1037, 1443 Ramos:* Batangas Province, *Merrill Phil. Pl. 1897, For. Bur. 21562 Tamesis:* Tayabas Province, *Bur. Sci. 26735 Ramos, For. Bur. 10267 Curran, Merrill 3356.* MINDORO, *Cuming 1552.* PALAWAN, *Bur. Sci. 15541 Fenix.* BANCALAN, *Weber.* BALABAC, *Weber.* SAMAR, *For. Bur. 24655 Lasquety.* MASBATE, *Merrill 3064.* PANAY, *For. Bur. 15125 Cenabre.* MINDANAO, Bukidnon Subprovince, *Bur. Sci. 24946 Fenix.* In primary forests at low altitudes, often common.

ILLUSTRATION

PLATE 1. *Elaeodendron viburnifolium* (Juss.) Merr. Photograph of the type specimen in the herbarium of the Paris Museum of Natural History.

453

PLATE 1. ELAEODENDRON VIBURNIFOLIUM (JUSS.) MERR.

SOME ASPECTS OF THE SALT REQUIREMENTS
OF YOUNG RICE PLANTS [1]

By Rafael B. Espino

Of the College of Agriculture, Los Baños

ONE PLATE AND NINE TEXT FIGURES

INTRODUCTION

One of the most important human activities has long dealt with the improvement of methods for securing plant products upon which human nutrition depends. The scientific problems of the nutrition of plants are thus closely connected with the practice of agriculture, and agriculturists as well as plant physiologists have already accomplished much toward outlining and solving some of these problems, with reference to many different kinds of plants. The mineral nutrition and the salt requirements of plants have recently received a great deal of attention, and the methods employed in experimentation in this field are being rapidly improved. Among the methods that have yielded valuable results as to the physiological needs of plants the so-called "water-culture" method is important. By this method the culture plants are grown with their roots in aqueous solutions of various inorganic salts, in various proportions, these solutions having various total concentrations. This may be called the method of solution cultures, although of course the source from which the plants absorb their mineral nutrients is an aqueous solution even when soil or sand is used. "Water culture" is employed in a general sense to denote such solution cultures, but, as Shive [2] has pointed out, actual water cultures (with distilled or otherwise purified water) are seldom of much value in nutritional experimentation, partly because pure water not

---

[1] Botanical contribution from the Johns' Hopkins University, No. 61. A brief preliminary report of some of the results presented in this paper was given before the 1918 (Baltimore) meeting of the Physiological Section of the Botanical Society of America.

[2] Shive, John W., A study of physiological balance in nutrient media, Physiol. Res. 1 (1915) 327–397, 331. See also True, R. H., Harmful action of distilled water, Am. Journ. Bot 1 (1914) 255–273; Hibbard, R. P., The question of the toxicity of distilled water, ibid. 2 (1915) 389–401.

only does not supply the mineral salts needed by the plant, but it also acts to remove salts already within the plant body. The study to be reported in this paper deals with the growth of young rice plants (*Oryza sativa,* variety "Wateribune") in aqueous solution cultures. No attempt will be made here to review studies made on culture solutions, but the readers are referred to Tottingham's [3] monograph which gives a very complete resumé of earlier solution-culture experimentation with plants and to later papers that appeared on the subject. A brief review, however, will be made of previous studies on rice which appear to have a direct bearing on the present problem.

REVIEW OF PREVIOUS EXPERIMENTS ON THE MINERAL NUTRITION OF RICE

The present studies deal with solution cultures, as has been said, and they may serve as a small contribution toward a better knowledge of this field of physiology. Such studies, however, must of course involve some particular kind of organism and the rice plant was chosen as the experimental subject, for several reasons. In the first place, it seemed that the extensive aspect of our knowledge of this phase of physiology deserved attention; there are so many different sorts of plants, and generalizations for all plants are perhaps too easily formed from knowledge of a few kinds. The aim was to select a plant that would probably show some important physiological differences from the ones thus far studied. At the same time the plant used should be one of considerable human interest, for plant production and the practical applications of plant physiology are always demanding more scientific knowledge than is available. These studies were to be purely physiological, but the plant used might well be one of agricultural interest. Also, of course, the plant selected must be suited to solution-culture experiments; soils, and even sand cultures, present problems that are so complicated as to be almost hopeless until some of the simpler problems offered by solution cultures become better understood. Choosing the experimental subject at a time when agricultural operations loomed very large on the world's horizon, when the whole of civilization was in the tightening grip of a quasi famine, it was natural first to consider what plants are

---

[3] Tottingham, Wm. E., A quantitive chemical and physiological study of nutrient solutions for plant cultures, Physiol. Res. 1 (1914) 133–245. See also Shive, J. W., The freezing points of Tottingham's nutrient solutions, Plant World 17 (1914) 345–353.

most important to the human race. If wheat be the most important, then perhaps rice may be the second. Wheat had been studied considerably, though much remains to be done with it, but rice had received no attention by the newer methods of solution culture. Also, various writers had presented evidence to the effect that rice differs from wheat and many other plants in that rice is able to utilize ammonium as a source of nitrogen. Rice also appeared to be well suited to solution cultures. Finally, rice is perhaps the most important plant in the writer's home country; it forms the main vegetable source of food for the great majority of the population of the Philippine Islands, and it is a very important agricultural crop there, as well as in many other parts of the world. Large amounts of it are grown in the southern and western United States, in Italy, India, Africa, Japan, Spain, etc. Lowland rice was selected for the experiments to be reported in this paper.

These studies may therefore be regarded as furnishing some contribution to our knowledge of the physiology of the rice plant, just as they contribute somewhat to our knowledge of solution culture and the mineral nutrition of plants in general. The recent intensive study of the mineral nutrition of plants, through the employment of the systematic schemes of Schreiner and Skinner (1910), Tottingham (1914), Shive (1915), and others, has not thus far included the rice plant, but several valuable studies of a less extensive and systematic sort have been reported for rice. The following paragraphs give a resumé of previous work on the salt nutrition of rice, with which the writer is familiar.

The problem of the mineral nutrition of rice immediately brings up the question of ammonium salts as possible sources of nitrogen for plant nutrition. It appears that plants differ in regard to their ability to utilize ammonium salts. An early publication dealing with this question is that of Bouchardat.[4] He employed culture solutions with several forms of inorganic ammonium compounds ("sesquicarbonate," bicarbonate, sulphate, "chlorhydrate," and nitrate of ammonium) and experimented on the growth of *Mimosa pudica* in these solutions. He concluded that the ammonium salts used were not only useless as sources of nitrogen for the plant employed, but that they were highly toxic when supplied in certain concentrations. It was

---

[4] Bouchardat, A., De l'action des sels ammoniacaux sur la vegetaux, Compt. Rend. Acad. Sci. Paris 16 (1843) 322–324.

over thirty years later that Lehmann [a] published an account of experiments which seemed to show that ammonium sulphate may be a source of nitrogen for certain higher plants. He employed solution cultures and supplied all the necessary elements in all cases, but some cultures were furnished with nitrogen as a nitrate (calcium nitrate), while the nitrogen of others was supplied as an ammonium salt (ammonium sulphate). He observed that maize plants developed normally for forty-one days (from the seed) in solutions containing ammonium sulphate, while the plants with calcium nitrate showed only poor growth during that period. After this first period of forty-one days, however, his "nitrate" plants recovered and continued with good growth, while his "ammonium" plants became chlorotic and sickly. Also, Lehmann observed that the chlorotic plants of his nitrate group within the first forty-one day period might be made to assume normal growth and appearance, if they were transplanted to a culture solution containing ammonium sulphate; in two days they became green. Furthermore, when healthy plants of his ammonium group were similarly transplanted to a solution containing sodium nitrate, they soon became pale and sickly.

The same author obtained similar results with tobacco plants grown in sand cultures. He supplied the necessary minerals, furnishing nitrogen either as ammonium sulphate or as sodium nitrate. The plants grown in the medium containing ammonium sulphate were healthy and grew normally from the beginning to the end of the experiment. Those supplied with nitrogen as sodium nitrate were chlorotic and unhealthy during the first half of the vegetative period, but they afterwards became green and vigorous, although the final yield was much lower than that obtained from the cultures with ammonium sulphate as the source of nitrogen.

Lupine plants grown in sand cultures in Lehmann's experiments gave better vegetative growth when nitrogen was supplied as sodium nitrate than when it was furnished as ammonium sulphate, but the yield of seed was larger in the latter case.

From these studies Lehmann came to the conclusion that some plants require nitrate nitrogen, others require ammoniacal nitrogen, and still others require one of these two forms of nitrogen during the early stages of growth and the other form during the later stages. While the experimentation on which

[a] Lehmann, Jul., Ueber die zur Ernährung der Pflanzen geeignetste Form des Stickstoffes, Biedermann's Centralbl. Agr.-Chem. 7 (1875) 403–409.

Lehmann based these conclusions would not now be considered as convincing in itself, yet his general conclusions still appear to stand. Of course the modern problem of the nitrogen requirements of plants involves not only nitrates and ammonium salts, but also nitrites and many other compounds containing nitrogen, and must take account of such topics as nitrification, denitrification, and the assimilation of elemental nitrogen. The question regarding the direct utilization of ammonium salts by specific agricultural plants bids fair to maintain an important position in agronomic discussions for a long time to come. It will of course be necessary that each important kind of plant be made the subject of special and rather elaborate experimentation.

Without here attempting to summarize the literature of this broad subject, attention may be directed to Hutchinson and Miller's [6] experiments and to their discussion. They grew wheat and peas in solution culture and also in sand culture. They conclude that—

* * * agricultural plants of various kinds can produce normal growth when supplied with nitrogen in the form of ammonium salts under conditions which exclude the possibility of nitrification. Some plants grow equally well with ammonium salts or nitrates as source of nitrogen. Other plants, while assimilating ammoniacal nitrogen in the absence of nitrates, appear to prefer nitrates. It is less certain whether ammonium salts can ever produce better final results than nitrates although we have indications that this may be the case.

In connection with the doubt expressed by Hutchinson and Miller, "whether ammonium salts can ever produce better final results than nitrates," the studies on rice by Nagaoka, Kelley, and others, which will be mentioned later, are of interest.

Turning to the rice plant in particular, the problem of its salt nutrition has been touched upon from almost all angles, but in a rather hit-and-miss way. Kellner [7] conducted perhaps the first solution-culture experiments on lowland rice, with the aim of determining whether this plant thrives best with one or another form of nitrogen-bearing salt. He grew his plants in nutrient solutions supplying all the essential chemical elements for normal growth of ordinary higher plants. In one solution nitrogen was supplied as potassium nitrate, and in another as ammonium sulphate, and his experiments were repeated several

[6] Hutchinson, H. B., and Miller, N. H. J., Direct assimilation of ammonium salts by plants, Journ. Agr. Sci. 3 (1909) 179–194.

[7] Kellner, O., Agriculturchemische Studien über die Reiscultur, Landw. Versuchsst. 30 (1884) 18–32.

times, using the same salts but varying the amounts. He concluded that paddy rice in the early stages of its development grew better in a nutrient medium supplied with ammoniacal nitrogen than in one supplied with nitrate nitrogen, while during the later stages of development the nitrate proved to be a better source of nitrogen than was the ammonium salt. He also tried culture solutions containing the other necessary elements and having the ammonium salt and the nitrate both present at once, and found that the combination of these forms of nitrogen gave better growth than did either form alone.

The beneficial effect of ammonium sulphate, as well as the unsuitability of nitrates as sources of nitrogen for rice, were also observed by Nagaoka,[8] who carried out a series of rather extensive pot and plot experiments with upland and lowland varieties of rice grown to maturity. He began his cultures with plants about 42 days old, so that the plants had passed beyond the first stages of growth before they were tested. By means of pot cultures with soil he compared the growth and the yield of a lowland rice supplied with different amounts of ammonium sulphate with those of the same variety supplied, separately, with one of the salts, sodium nitrate, potassium nitrate, calcium nitrate, barium nitrate, strontium nitrate, and magnesium nitrate. He found that plants grown in the media supplying nitrogen in the form of ammonium sulphate alone were green and produced much tillering (branching at the base of the stem), while plants "fed" with one of the nitrates were yellowish and produced but little tillering. The six nitrates tested were about alike in this effect. Nagaoka observed, however, that the seed ripened ten days earlier when the plants had been supplied with a nitrate than when they had been supplied with the ammonium salt.

The field-plot experiments of Nagaoka were planned to study the fertilizer values of sodium nitrate and ammonium sulphate. In these experiments he applied one or the other of the two salts to the soil. The fertilizer application was made before planting and also at intervals during the growth of the plants. Lowland rice was again used and, as in his previous pot experiments, the yield obtained showed that ammonium sulphate was about two and one-half times as good as sodium nitrate in this respect.

In another set of pot experiments, with upland as well as low-

[8] Nagaoka, M., On the behavior of the rice plants to nitrates and ammonium salts, Bull. Coll. Agr. Imp. Univ. Tokyo 6 (1904) 285–334.

land rice, Nagaoka used a soil to which a fertilizer without nitrogen was similarly applied in all cases. To the pots of one group he added different amounts of sodium nitrate, and to those of another group he added different amounts of ammonium sulphate. Some of the pots of each treatment were kept wet, as in rice paddies, while in other pots the soil was kept merely moist. The results obtained showed that ammonium sulphate gave better yields than did sodium nitrate, for both forms of rice and for both soil-moisture conditions. The ammonium salt was always absorbed to a greater extent than was the nitrate, but the upland variety absorbed more sodium nitrate than did the lowland variety. As to the moisture content of the soil, both varieties gave good yields in either one of the two moisture conditions studied, but the results were better with lowland rice in wet soil and with upland rice in merely moist soil.

The apparent failure of the rice plant to utilize nitric nitrogen and its apparent preference for the ammoniacal form were ascribed by Nagaoka to the fact that paddy rice does "not accumulate a sufficient quantity of sugar in the leaves to convert all of the nitric acid absorbed into protein." The chlorotic appearance of the plants supplied with nitrogen solely as nitrates might be "due to the physiological influence of accumulated nitrates." Nagaoka pointed out that the soil of pots receiving large additions of nitrate gave a slight nitrite reaction, and he suggested that denitrification (resulting in the formation of nitrites from nitrates in the soil) might take place in the rice paddy through the action of microörganisms, so that the excessive amount of nitrites thus formed might poison the plants.

Daikuhara [9] also found that the application of certain ammonium compounds to the soil was beneficial to rice. He used sand cultures to which limestone and magnesium sulphate were added in various proportions. He also added sodium nitrate to one pot and ammonium sulphate to another. To a third pot ammonium nitrate was added. The total yield (grain and straw) showed that, under the conditions of the experiment, ammonium sulphate was about two and one-half times as beneficial as was sodium nitrate, thus confirm'ng the general conclusion of Nagaoka. Daikuhara found also that the fertilizer value of ammonium nitrate was intermediate between the values of ammonium sulphate and sodium nitrate.

    [9] Daikuhara, G., On the application of magnesium in the form of magnesium sulphate for the needs of the rice plant, Bull. Imp. Central Agr. Exp. Sta. Japan 1 (1905) 24–29.

Aso and Bahadur [10] found that a combination of ammonium sulphate and disodium phosphate produced better results with paddy rice in the field than did combinations of any other salts in their tests.

Krauss [11] also reported results from pot and field experiments with rice, indicating that (of the different nitrogenous fertilizers that he tested) ammonium sulphate ranked above calcium nitrate and sodium nitrate by the criterion of yield of grain.

The superior fertilizer value of ammonium sulphate, as compared with the values of sodium nitrate, calcium nitrate, magnesium nitrate, and ammonium nitrate, was also noted for the rice plant by Kelly.[12] He employed lowland rice in both field and pot cultures, adding nitrogenous fertilizers before planting and, in other cases, at intervals during the culture period. The cultures supplied with ammonium sulphate showed good growth and gave good yields of both straw and grain, while those in which nitrogen was supplied to the soil only as sodium nitrate gave but low yields. Apparently this nitrate was ineffective as a fertilizer. He also found that the ammonium salt applied before planting proved more beneficial than did the same salt applied at intervals during the culture period. In pot cultures the addition of nitrate to the soil proved beneficial in the latter part of the growth period, from near the flowering stage to maturity. This last observation agrees with that recorded for maize by Lehmann (1875). Kelly suggested that this difference in the response of the rice plant to soil fertilization with sodium nitrate and with ammonium sulphate, might be due to the fact that the lowland rice plant "has in a large measure lost the power of reducing nitrates," which, in turn, might be due to the fact that this plant has been "grown for centuries under conditions that largely exclude the formation of nitrates." While these considerations may be of interest in connection with genetics and phylogeny, still the physiological reasons for the observed state of affairs (which must be sought in the plant itself) remain untouched. From the standpoint of genetics it may be asked whether the paddy rice plant ever had the power of reducing nitrates. Kelley appreciated the unsatisfactory sta-

[10] Aso, K., and Bahadur, R., On the influence of the reaction of the manure upon the yield, Bull. Coll. Agr. Imp. Univ. Tokyo 7 (1906) 39–46.

[11] Krauss, F. G., Ann. Rept. Hawaii Agr. Exp. Sta. 1907 (1907) 67–90. Ibid. 1908 (1908) 65–84.

[12] Kelley, W. P., The assimilation of nitrogen by rice, Hawaii Agr. Exp. Sta. Bull. 24 U. S. Dept. Agr., Washington, D. C., 1911.

tus of the problem, however, and ended his discussion by empha-
sizing the need for much more study along these lines; he said
that "further experiments will be conducted to determine the
correctness of this view," but this promise has apparently not
yet been fulfilled.

Similar beneficial effects of ammonium sulphate upon rice
plants were observed by Daikuhara and Imaseki,[13] with pot cul-
tures. They found that ammonium sulphate alone was superior
to sodium nitrate alone and also to a combination of these two
salts.

From field experiments W. H. Harrison[14] concluded that ni-
trates were unsuitable for rice, but that ammonium compounds,
or manures that yield ammonia under anaërobic conditions of
fermentation, were of great value.   J. B. Harrison,[15] on the other
hand, reported that the application of ammonium sulphate to field
plats of rice resulted in a decreased yield. This lower yield, how-
ever, was thought to be due to lodging, which occurred on account
of the very luxuriant growth that took place in the plats sup-
plied with ammonium sulphate rather than to any directly in-
jurious effect of the salt.

Further experimental evidence in favor of the idea that
ammonium salts are good sources of nitrogen for rice is avail-
able from later work by Kelley,[16] who conducted a series of
field trials. Ammonium sulphate was added to one plat and
sodium nitrate to another, the addition being made before the
time of planting. To the soils of other plats nitrogenous fer-
tilizers were added from time to time during the development
of the plants. The results agreed in indicating the superiority
of ammonium sulphate over sodium nitrate. Kelley concluded
that—

a complete fertilizer proved no more effective than ammonium sulphate
alone, whereas the application of both ammonium sulphate and potas-
sium sulphate caused a decrease as compared with that obtained from
ammonium sulphate alone.

[13] Daikuhara, G., and Imaseki, T., On the behavior of nitrate in paddy
soils, Bull. Imp. Central Agr. Exp. Sta. Japan 1 (1907) 7–36. (Cited by
Kelley, 1911.)

[14] Harrison, W. H., The principles of paddy manuring, Journ. Board
Agr. Brit. Guiana 6 1 (1912) 37–40. Ibid. 6 2 (1912) 71–77.

[15] Harrison, J. B., Experiments with varieties of rice at the Botanic
Garden, 1912, Journ. Board Agr. Brit. Guiana 7 (1913) 42–43.

[16] Kelley, W. P., Rice soils of Hawaii: Their fertilization and manage-
ment, Hawaii Agr. Exp. Sta. Bull. 31 U. S. Dept. Agr., Washington, D.
C. (1914).

Besides the various nitrates and ammonium salts, other forms of nitrogen-bearing substances have been tried with rice, but a review of the literature on these will not be given here.

SUMMARY

From the foregoing review of the more definite contributions that have been made toward a knowledge of the mineral nutrition of rice, it appears that there is good reason to suppose that:

(1) This plant requires the same chemical elements as do other higher plants.

(2) The young plants are not suited to deriving their nitrogen from nitrates but thrive very well when ammonium sulphate (or probably other ammonium salt, such as the chloride, nitrate, etc.) is supplied.

(3) Older plants are able to derive their nitrogen supply from nitrates, but may be able to thrive without the nitrate ion when the ammonium ion is supplied at a proper rate.

None of the points just mentioned is at all well established in a quantitative way; much of the experimentation on which our present knowledge of these matters is based has been carried on with field soils, whose various properties were mostly unknown, so that (for this reason among others) the results of different experimenters are generally not logically comparable. The apparent importance of the relation between nitrate and ammonium as sources of nitrogen for young rice plants, and of the question regarding the physiological balance for rice between the three main kations that are generally required by plants (potassium, calcium, and magnesium), makes it appear that more attention needs to be given to the simpler physiological aspects of these relations. It was with these points particularly in mind that the solution-culture studies on rice seedlings here to be reported were undertaken. This work is presented as a beginning only. As is general in such cases, the experimental analysis is very incomplete and probably more questions are raised than are answered, even in a preliminary way. In spite of the enormous amount of work needed to obtain satisfactory conclusions regarding the physiological problems dealt with by the solution-culture method, it seems obvious that the relations of any given plant form to the soil in which it is growing will hardly be understood at all well before the behavior of that plant toward free solutions has been rather thoroughly worked out. Furthermore, if the problems of plant nutrition that are

presented by solution cultures are complex, those presented by soil cultures are many times more complex. While field experimentation with agricultural plants will of course go on in large volume, for economic reasons it seems desirable that the simpler physiological problems that may be attacked by solution cultures should be dealt with whenever opportunity allows. It should be repeatedly emphasized that the aim of study of this sort is to bring about a better understanding of the nutritional requirements of the plants considered, not to give information regarding the fertilizer treatment of soils. After the plant itself is fairly well understood when growing under the simplest possible sets of conditions, then soil experimentation may perhaps be planned so as to furnish results directly valuable in field culture. The studies here reported deal simply with the rice plant as a machine, and the solution-culture method offers the simplest form of satisfactory root environment that can be devised. The problems of the physical and chemical characteristics of any soil that might be employed are here avoided altogether.

GENERAL SURVEY OF THE PRESENT STUDY

These studies were planned to throw some light on the salt relations of young lowland rice plants when grown in solution cultures in a greenhouse. It was proposed, first, to find out whether any set of salt proportions and total concentrations possible with the 3-salt type of solution, studied by Shive, might be suitable for good growth of the young rice plants. As was already foreshadowed in the results of earlier workers with rice, it turned out that it is impossible to obtain good growth of this plant (for the first few weeks of its growth from the seed) in any one of these 3-salt solutions.

It was then proposed to supply the plants with the ammonium ion, following the suggestions of the literature. This was done by employing the single ammonium salt, ammonium sulphate; other ammonium salts were not tested. Since ammonium is a kation, and since there is no question but that the rice plant requires all three of the main kations (potassium, calcium, and magnesium) needed by higher plants in general, it logically follows that ammonium cannot be directly supplied in a complete, nutrient solution unless the latter contains four salts. The second stage of these studies therefore dealt with a 4-salt type of solution containing the four kations (potassium, calcium, magnesium, and ammonium) as well as the generally requisite anions (nitrate, phosphate, and sulphate). Many different sets

of salt proportions and a number of different total concentrations of this 4-salt type of nutrient solution were tested, and certain ones of these proved to be excellent for the plants employed.

The question then arose, whether the presence of the nitrate ion in the medium might not be either unnecesary or even positively harmful to the young rice plants, and the third stage of these studies dealt with still another 4-salt type solution, which contained all the generally necessary mineral elements but contained no nitrate. Nitrogen was supplied here only as ammonium sulphate. This type of solution was also tested with many different sets of salt proportions and with a number of different total concentrations. The results showed that some of these solutions gave very good general growth, but the best of them were not as good as the best ones containing nitrate; this type of solution always produced a characteristic leaf injury.

The work here reported was carried out in the Laboratory of Plant Physiology of the Johns Hopkins University; and the writer's acknowledgments and thanks are hereby expressed for the facilities of that laboratory, and for instruction, advice, and guidance given him by Prof. B. E. Livingston and Dr. H. E. Pulling.

EXPERIMENTATION

SEEDS AND SEEDLINGS

The rice used in this study was kindly furnished by the United States Department of Agriculture. It is of the lowland type bearing the name "Wateribune," and this stock of seed was grown, under irrigation, at the Crowley Station of the Louisiana Agricultural Experiment Station. This variety is often grown on a small scale without irrigation in the Southeastern States, but always with very moist soil.

In starting an experimental series, about two thousand seeds were first placed in about 300 cubic centimeters of tap water in an open glass pan (15 centimeters in diameter), where they were allowed to soak for twenty-four hours. They were then placed between folds of wet absorbent paper (paper toweling, about like thin filter paper), where they remained another twenty-four hours. At the end of this period germination was visibly beginning so that the plumule protruded slightly. The germinating seeds were next distributed on a net of paraffined cotton threads (mosquito netting, mesh about 1.5 millimeters square), which was stretched horizontally over the opening of a cylindrical earthen jar (55 centimeters in diameter and 40

centimeters deep). The jar was kept full of tap water so that the seeds were supported at about the surface of the liquid. Unlike wheat, this rice does not ferment rapidly when the water about it remains unchanged, and this fact, together with the large volume (about 90 liters) of water lying below the seeds, made it seem unnecessary to change the water during the germination period. The germination jar stood in a greenhouse room, exposed to sunlight. The seedlings remained on the net till the shoots were from 3 to 5 centimeters long, requiring a period of from ten to fifteen days, depending on weather conditions, especially temperature.

At the end of the germination period uniform and apparently vigorous seedlings were selected for the cultures.[17] These were placed in a dish of tap water, from which they were taken one by one, and mounted in paraffined cork stoppers of the form used by Shive (1915). Each stopper had six holes and six seedlings were held, one in each hole, by means of properly compressed plugs of cotton. These preparations were then put in place in the openings of the culture bottles, which were of the 250 cubic centimeter form used by Shive (1915). Cardboard covers like the ones described by that writer (1915) were placed around the bottles so as to keep the interior nearly dark. Each bottle contained 250 cubic centimeters of the proper nutrient solution and the roots of the seedlings were almost entirely immersed in the liquid. The seeds were supported just beneath the lower surface of the stopper and were not in contact with the liquid.

SOLUTIONS

SINGLE-SALT STOCK SOLUTIONS

In preparing the culture solutions single-salt solutions of half-volume molecular [18] concentration were first prepared. The salts used were "Baker analyzed" monopotassium phosphate (KH_2PO_4), calcium nitrate [$Ca(NO_3)_2$], magnesium sulphate ($MgSO_4$), ammonium sulphate [$(NH_4)_2SO_4$] and monocalcium phosphate [$Ca(H_2PO_4)_2$].[18] No attempt was made to dry the salts or to determine their water contents, the data on water

---

[17] On internal differences between seedlings that might be supposed to be alike, see Stiles, W., On the the relation between the concentration of the nutrient solution and the rate of growth of plants in water culture, Ann. Bot. 29 (1915) 89–96.

[18] The stock solution of monocalcium phosphate was twelfth-molecular instead of half-molecular.

content furnished on the label being taken as a basis for preparing the solution in each case. Doubtless some errors were introduced by this procedure. The study was to be only preliminary in character, however, and this kind of work always involves many unknown and uncontrollable conditions, some of which are surely more influential in determining the growth of the plants than are the errors introduced by employing the manufacturers' data on water content, so that special analyses (with their relatively great consumption of time) seemed undesirable in the present case. It was at first intended that samples of the single-salt stock solutions should be subjected later to quantitative determinations, in order to obtain their actual concentrations, but time was finally lacking for this. It is undoubtedly better, in work of this kind, to make up the solutions and then determine their concentrations by analytical methods, than to attempt to dry the salts to a known water content before dissolving. The errors here considered of course apply only to calcium nitrate, ammonium sulphate, and monocalcium phosphate; the other two salts are practically dry as they come on the market.

The ferric phosphate ($FePO_4$) used was prepared according to the procedure of Shive and Tottingham; that is, the ferric nitrate [$Fe(NO_3)_3$] was allowed to react with monopotassium phosphate (KH_2PO_4), forming the precipitate, which was then thoroughly washed with distilled water. The precipitate divides very finely and settles to the bottom of the container only after considerable time. When this material was needed for addition to the culture bottles (when new cultures were to be started or solutions were to be renewed) the bottle containing the precipitate and its supernatant water were thoroughly shaken so as to give a uniform suspension. Five cubic centimeters of this suspension, containing about 11 milligrams of ferric phosphate, were added to each 250 cubic centimeters of culture solution. The slight further dilution resulting from this addition of 5 cubic centimeters of water to each 250 cubic centimeters of culture solution was regarded as insignificant.

The distilled water used was that of the laboratory, derived from a Barnstead still, the same as was used by Hawkins,[19] Shive (1915), and Tottingham (1914).

[19] Hawkins, Lon A., The influence of calcium, magnesium and potassium nitrates upon the toxicity of certain heavy metals toward fungus spores, Physiol. Res. 1 (1918) 57–92.

THE STOCK CULTURE SOLUTIONS

Three types of nutrient solution were studied:

(1) The 3-salt type studied by Shive (1915, 1917) with wheat and buckwheat,[20] which has been called the 3-salt type I by Livingston and Tottingham.[21] This contains, besides a small amount of ferric phosphate, the three salts monopotassium phosphate, calcium nitrate, and magnesium sulphate.

(2) A 4-salt type with both ammonium and nitrate. This contains, besides ferric phosphate, the four salts monopotassium phosphate, calcium nitrate, magnesium sulphate, and ammonium sulphate. It will be termed the 4-salt type A.

(3) A 4-salt type with ammonium but without nitrate. This contains, besides ferric phosphate, the four salts monopotassium phosphate, monocalcium phosphate, magnesium sulphate, and ammonium sulphate. It will be termed the 4-salt type B.

For each of these three types stock culture solutions were prepared from the requisite single-salt stock solutions and distilled water, the total concentrations of the stock culture solutions of each type being alike and as high as that used for the most concentrated culture solution. No ferric phosphate was added to the stock culture solutions. For each type there were as many of these stock solutions as there were different sets of salt proportions in the list to be tested. From any given stock culture solution the various total concentrations needed for the cultures employing that particular set of salt proportions could be readily obtained, either directly or by simple dilution. These concentrated stock culture solutions were stored in much-used glass bottles (of about 3.5 liters' capacity), practically in darkness, and they were drawn upon from time to time as the culture solutions were renewed. In the case of the 3-salt type these stock culture solutions were kept for about a month; in the case of the two 4-salt types they were kept twice as long. In no case was there any evidence suggesting alteration in the stock solutions; at least none beyond the occasional appearance of small fungus colonies, which were always removed with a glass tube as soon as they became conspicuous.

The employment of concentrated stock culture solutions from which the actual culture solutions were obtained, by simple dilution—a procedure that saves very much time, tends to simplify the culture work, and avoids the possibility of many errors

[20] Shive, John W., A study of physiological balance of buckwheat grown in three-salt solutions, New Jersey Agr. Exp. Sta. Bull. 319 (1917) 5-63.
[21] Livingston, B. E., and Tottingham, Wm. E., A new three-salt nutrient solution for plant culture, Am. Journ. Bot. 5 (1918) 337-346.

—was made possible in these studies by the adoption of a new method of dealing with salt proportions. Whereas Tottingham, Shive, and others have based their salt proportions on the partial osmotic values of the various component salts (thus involving the principle of increased dissociation with greater dilution), the salt proportions of the present studies were considered without regard to ionization and were stated simply as molecular salt proportions. All stock culture solutions for any given type were planned to contain the same number of salt molecules per unit of volume; they differed from one another only in the manner in which this number was apportioned among the three or four different kinds of molecules (salts). When this method is adopted the several salts are placed together in the stock culture solution, with a certain set of molecular salt proportions, and the addition of water to this solution does not alter these proportions; they remain the same for all dilutions of this stock solution, although the total concentration is changed by the dilution process. This method of treatment does not at all imply that the various molecules of salt all remain intact in the mixed solution; it is of course appreciated that dissociation must be supposed to occur, and to a higher degree with successively lower total concentrations; but the degree of dissociation of each of the component salts in any culture solution becomes a matter for special study and does not enter into the simple description of the solution.

It can be seen that this plan makes it possible to state the salt proportions with much greater simplicity than can be attained when osmotic salt proportions are employed; that the statement of atomic proportions (and also of ionic proportions, calling an atomic group an ion whether or not it is dissociated from its molecule) is similarly simplified; and that any total osmotic value (total concentration) that is lower than that of the stock culture solution in question may be obtained for any given set of molecular salt proportions by simple dilution from the corresponding stock culture solution. Of course the osmotic value of any solution is determined, for any temperature, etc., by (1) the salts employed, (2) their molecular proportions, and (3) their various degrees of ionization. This value may be approximately calculated by making certain assumptions, but the most satisfactory way to determine it is by means of the freezing-point method. All osmotic values mentioned in this paper are merely rough approximations derived from the values obtained by Tottingham and Shive for somewhat similar mix-

tures. Lack of time prevented the actual determinations of the freezing points of the solutions used in these experiments.

The three series of stock culture solutions will now be described in order.

Three-salt type I.—Fifteen different sets of molecular salt proportions were tested for this solution type. The fifteen different stock culture solutions all agree in having a total of 0.0245 gram-molecule of salt per liter and the molecular partial concentration of each of the three salts differs from solution to solution throughout the series by increments of one-seventh of the total molecular concentration; that is, by increments of 0.0035 gram-molecule. These fifteen different 3-salt stock solutions may be designated according to the positions of the points representing them on a 3-coördinate diagram similar to the one used by Schreiner and Skinner, Shive, and others. The diagram here used is shown in fig. 1. The different sets of molecular salt proportions will be named by formulas similar to those employed by Shive, only that the letter S will be here used (for solution) instead of C (for culture). R1S1 is the solution represented by the lower left apex of the triangular diagram; R1S3 is the one represented by the third point from the left end of the lowest row of points; R3S3 is represented by the third point, counting from the left, in the third row; R5S1 is represented by the top apex of the diagram (since the fifth row has but a single point), etc. In this diagram every solution of the lowest row has one-seventh of its total molecular concentration made up of monopotassium

Fig. 1. Relative values of top length for series 4, with 3-salt solution type I (increments of one-seventh, total concentration of 0.0061 gram-molecule per liter or 0.23 atmosphere). Lightly shaded area includes best-balanced sets of salt proportions, heavily shaded area includes poorest sets.

phosphate, every one on the left margin has one-seventh made up of calcium nitrate, and every one on the right margin has one-seventh made up of magnesium sulphate.

The different sets of molecular salt proportions and the molecular partial concentrations of the one salt monopotassium phosphate are shown in Table 1. From these data the molecular partial concentrations of the other two salts can be readily computed.

171114——8

TABLE 1.—*Description of stock culture solutions of 3-salt type I.*

[Total concentration 0.0245 gram-molecule (of all salts taken together) per liter.]

Solution No.	Molecular salt proportions KH₂PO₄ Ca(NO₃)₂ MgSO₄.	Volume of molecular partial concentration of KH₂ PO₄.	Solution No.	Molecular salt proportions KH₂PO₄ Ca(NO₃)₂ MₓSO₄.	Volume of molecular partial concentration of KH₂ PO₄.
R1S1	1:1:5		R3S1	3:1:3	
S2	1:2:4		S2	3:2:2	0.0105
S3	1:3:3	0.0035	S3	3:3:1	
S4	1:4:2		R4S1	4:1:2	
S5	1:5:1		S2	4:2:1	0.0140
R2S1	2:1:4		R5S1	5:1:1	0.0175
S2	2:2:3				
S3	2:3:2	0.0070			
S4	2:4:1				

Four-salt type A.—(Monopotassium phosphate, calcium nitrate, magnesium sulphate, ammonium sulphate). Thirty-five different sets of molecular salt proportions were tested for this solution type. The thirty-five stock culture solutions all agree in having a total of 0.0384 gram-molecule of salt per liter and the molecular partial concentration of each of the four salts differs from solution to solution throughout the series by increments of one-eighth of the total molecular concentration; that is, by increments of 0.0048 gram-molecule. These thirty-five different 4-salt stock solutions may be designated according to the positions of the points representing them on a 4-coördinate (solid) diagram similar to the one used by Tottingham. The diagram here used is shown in fig. 2. It is like that employed by Tottingham except that the several equilateral triangles on which the equilateral tetrahedron is built are here represented somewhat in perspective and are placed one above the other, the tetrahedron itself being indicated in outline and having its vertical axis represented as much longer than the other axes, in order to accommodate for the perspective views of the component triangles. Tottingham represented the several triangles all on the same plane,
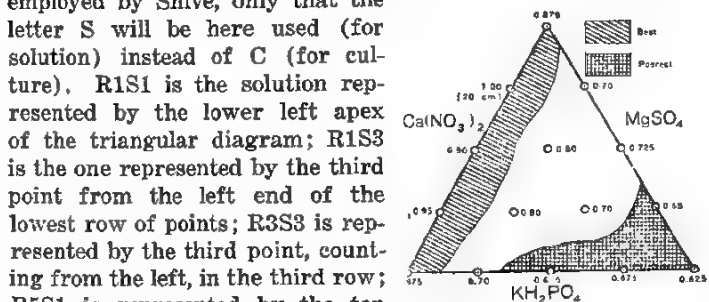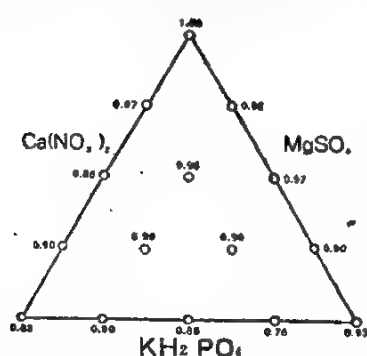

Fig. 2. Relative values of root length for series 4, with 3-salt solution type I (increments of one-seventh, total concentration of 0.0061 gram-molecule per liter or 0.23 atmosphere).

where they could be drawn as equilateral without distortion.
The different sets of molecular salt proportions will be named
by formulas similar to those employed by Tottingham, the letter
S being here used in place of the C in his formulas.   T1R1S1
is the solution (or set of salt proportions) represented by the
lower front apex of the diagram; T1R2S4 is the one represented
by the fourth point, counting from the left, in the second row
from the front of the lowest triangle; T3R1S2 is represented
by the second point, counting from the left, in the front row
of the third triangle from the bottom; T5R1S1 is represented
by the top apex of the tetrahedron (since the fifth triangle has
but a single point), etc.   In this diagram every solution of the
lowest triangle has one-eighth of its total molecular concentra-

TABLE 2.—*Descriptions of stock culture solutions of 4-salt types A and B
(A, with both ammonium and nitrate; B, without nitrate).*[a]

[Total concentration, 0.0384 gram-molecule (of all salts taken together) per liter.]

Solution No.	Molecular salt proportions KH2PO4 (NH4)2 SO4Ca (NO3)2 MgSO4.	Volume of molecular partial concentration of KH2PO4	Solution No.	Molecular salt proportions KH2PO4 (NH4)2 SO4Ca (NO3)2 MgSO4.	Volume of molecular partial concentration of KH2PO4.
T1R1S1	1:1:1:5		T2R1S1	2:1:1:4	
S2	1:1:2:4		S2	2:1:2:8	
S3	1:1:3:3		S3	2:1:3:2	
S4	1:1:4:2		S4	2:1:4:1	
S5	1:1:5:1		R2S1	2:2:1:3	
R2S1	1:2:1:4		S2	2:2:2:2	
S2	1:2:2:8		S3	2:2:3:1	0.0096
S3	1:2:3:2	0.0048	R3S1	2:3:1:2	
S4	1:2:4:1		S2	2:3:2:1	
R3S1	1:3:1:3		R4S1	2:4:1:1	
S2	1:3:2:2		T3R1S1	3:1:1:3	
S3	1:3:3:1		S2	3:1:2:2	
R4S1	1:4:1:2		S3	3:1:8:1	
S2	1:4:2:1		R2S1	3:2:1:2	0.0144
R5S1	1:5:1:1		S2	3:2:2:1	
			R3S1	3:3:1:1	
			T4R1S1	4:1:1:2	
			S2	4:1:2:1	0.0192
			R2S1	4:2:1:1	
			T5R1S1	5:1:1:1	0.0240

[a] The salts named are those of type A; for type B, monocalcium phosphate replaced calcium nitrate as here given.

tion made up of monopotassium phosphate, each of those of the front margin of each triangle has one-eighth made up of ammonium sulphate, every one of the left margin of each triangle has one-eighth made up of calcium nitrate, and every one of the right margin has one-eighth made up of magnesium sulphate, etc. The solution at the top apex of the solid diagram (T5R1S1) has the salt monopotassium phosphate represented by five-eighths of its total molecular concentration, while each of the remaining three salts is represented by only one-eighth of the total.

The different sets of molecular salt proportions for solution types A and B, and the molecular partial concentrations of the one salt monopotassium phosphate, are shown in Table 2. From these data the molecular partial concentrations of the other three salts can be readily computed.

Four-salt type B.—(Monopotassium phosphate, monocalcium phosphate, magnesium sulphate, ammonium sulphate.) This type of solution differs from type A only in this particular, that it contains no calcium nitrate but has its calcium supplied as monocalcium phosphate. While type A contains both ammonium and nitrate as the nitrogen-bearing ions, type B contains only ammonium. Type B was studied in the same way as type A and the solution designations, salt proportions, total molecular concentrations, etc., are alike for the two types.

THE CULTURE SOLUTIONS

Each time a supply of culture solution was required, for starting a culture or for the renewal of its solution, this supply was prepared by merely drawing off some of the corresponding stock solution (in a few cases) or else by diluting some of that stock solution, the degree of dilution being of course determined by the total concentration required for the particular culture in question. Finally, after the solution for any series had been placed in the culture bottles, the ferric phosphate suspension was added. The culture solutions thus prepared were not stored in quantity and each lot was always placed at the disposal of the plants within twenty-four hours after it had been made up.

In renewing the solutions a set of culture bottles were first prepared and filled with their respective solutions. Then each cork, bearing its plants, was transferred from the bottle used during the previous period to the corresponding bottle of the newly prepared set. The plants were thus out of solution only momentarily.

Since the physical, chemical, and physiological properties of any complex solution depend (for any temperature, etc.) upon (1) the nature of the solutes contained, (2) their proportions in the mixture, and (3) the total concentration of the solution,[22] it is of course necessary, in such a study as this, to make comparisons between various nutrient solutions not only with reference to the kinds of salts used and their proportions in the solution, but also with reference to total concentration. It was therefore planned to determine approximately the best total concentration (for the growth of these seedling rice plants under the non-solution conditions employed for each culture series) for each set of salt proportions tested. This means that several different degrees of dilution of each one of the thirty-five stock culture solutions already characterized, had to be employed. Table 3 shows the different total concentrations that were actually used in each case. It also shows the time of year when each series of tests was made, as indicated by the dates. The different series are set forth under each of the three solution types in the order of their total concentrations.

During the culture period the culture solutions were renewed at intervals of three or four days, after the first five days. In connection with this sort of work it should not be forgotten that a given solution begins to alter in respect to its chemical and physical properties as soon as it is brought into contact with the plant roots, and that this alteration continues (in unknown ways) until the old, altered solution is removed and replaced by a fresh one having the standard properties of the old one at the start. The supply of the various ions and molecules at the absorbing surfaces of the roots is of course determined by the respective partial concentrations of these in that

[22] Different writers state this generalization in various ways, frequently from a distinctly not all-inclusive point of view. Some misunderstandings as to the nature of the questions involved and considerable resultant discussion have occurred in the literature, but the matter is too complicated for the present writer to attempt a broad discussion of it here. Especially have students of solution cultures given particular attention to these three controlling conditions as related to the physiological value of a nutrient solution. Whatever may prove to be the most useful way of giving quantitative values to these conditions, it seems quite clear that a plant growing in an aqueous solution may be made to grow faster or slower, better or worse, by altering any one, or two, or all three, of these characteristics of the solution; provided of course that other environmental conditions are not altered in a compensating manner, that the change or changes in the solutions are sufficiently great, and that the changed conditions are maintained for a sufficient length of time.

portion of the solution that lies closely adjacent to the root surfaces. These partial concentrations should of course be maintained constant in experiments of this kind, but the large

TABLE 3.—*Summary of the experimental series, showing dates, solution type, and total molecular concentration (also estimated osmotic value as a fraction of an atmosphere of pressure) for each series.*

Series.	Date (1918).				Total concentration.[a]					
	Beginning.		Ending.		3-salt type I.		4-salt type A.		4-salt type B.	
					Gram-molecule per liter.	Atmosphere.	Gram-molecule per liter.	Atmosphere.	Gram-molecule per liter.	Atmosphere.
1....	March	21	April	11	0.002	0.01				
2....	March	21	April	11	0.012	0.05				
3....	March	24	April	11						
4....	February	22	March	14						
5....	March	21	April	11	0.0061	0.23				
6....	March	24	April	11						
7....	March	21	April	11	0.0123	0.46				
8....	March	24	April	11						
9....	March	21	April	11	0.0245	0.93				
10[b]..	March	11	April	5	0.0002	0.01				
11....					0.0012	0.05				
12....					0.0061	0.23				
13....					0.0123	0.93				
14....	June	19	July	9			0.0008	0.04		
15....	May	24	June	14			0.0016	0.08		
16....	June	19	July	9						
17....	May	1	May	22						
18....	May	24	June	14			0.0038	0.20		
19....	June	19	July	9						
20....	June	19	July	9			0.0077	0.40		
21....	May	24	June	14			0.0192	1.00		
22....	May	1	May	22			0.0384	2.00		
23....	August	3	August	23						
24....	September	9	September	29					0.0008	0.04
25....	August	3	August	23						
26....	September	9	September	29					0.0016	0.08
27....	August	3	August	23						
28....	September	9	September	29					0.0038	0.20

[a] Total fraction of a gram-molecule of all salts per liter, and estimated osmotic value as a fraction of an atmosphere of pressure.

[b] Series 10, 11, 12, and 13 were with wheat, for comparison with the results obtained by Shive.

amounts of solutions needed and the work involved to accomplish this made it seem undesirable to attempt the use of continuously renewed solutions[23] in these preliminary studies; when

[23] Trelease, S. F., and Free, E. E., The effect of renewal of culture solutions on the growth of the young wheat plants in water-cultures, Johns Hopkins Univ. Cir. (March, 1917) 425 and 426.

the time is ripe for it, continuous renewal will surely be re-
sorted to. With the present state of knowledge and technic
it may be remarked that the solutions in culture bottles are
probably always in a state of convection, so that the solution
next to the roots is probably never very different from that
at a greater distance. It may therefore be supposed that the
culture solution alters as a whole and at a much lower rate
than would be the case close to the roots if convection were
prevented (as by the presence of sand, agar, etc.). Sufficiently
rapid convection would amount to continuous renewal of the so-
lution around any given root; and, if the volume of solution
held in the culture bottle is great enough (or if the alteration
in the solution, caused by the activity of the roots, is slow
enough), then the rate of alteration becomes insignificant, so
that the solution about the roots may be considered as being
practically maintained constant as to its properties. It has
frequently been mentioned in the literature that, if continuous
and rather rapid renewal of culture solutions is not employed,
the desideratum is more nearly approached with greater volume
of the solution (size of culture jar) and greater frequency of
renewal. In the present studies 250 cubic centimeters of so-
lution were always employed for six plants, and solution renewal
occurred at intervals of three or four days after the first five
days, as has been said. The experimental conditions would
of course have been more nearly ideal with a larger volume
and with more frequent renewal. It may well be that the
nature of the results obtained would have been insignificantly
different had the conditions been more nearly ideal, but the re-
sults presented below are to be regarded as applicable only
with reference to the general method here employed. With more
time and more work other and farther-reaching results might
surely be obtained, along this line as well as along other lines.

A chemical condition that is more or less definitely effective
within the liquid media of solution cultures, but that is seldom
or never adequately dealt with in this kind of work, is the
oxygen supply of the root systems. It is clear that most roots
require free oxygen [24]—that they are aërobic—and there is
reason to believe that rice [25] belongs in this class. It may be
conjectured, however, that the roots of young rice plants do

[24] Free, E. E., The effect of aëration on the growth of buckwheat in
water-cultures, Johns Hopkins Univ. Cir. (March, 1917) 198 and 199.
[25] Nagai, I., Some studies on the germination of the seed of Oryza sativa,
Journ. Coll. Agr. Imp. Univ., Tokyo 3 (1916) 109–158.

not require a very high partial concentration of oxygen in the solution in which they are growing, since these plants thrive excellently when rooted in mud containing large amounts of organic matter (reducing agents). No special method was employed to aërate the solutions in the tests here considered, but it may be assumed that all cultures were about alike in this regard and that the supply of oxygen to the root surfaces was considerable. The solutions were of course exposed to the air, for the corks bearing the seedlings were far from airtight. That good growth was obtained in some cultures indicates that the oxygen supply was adequate, at least with reference to the non-oxygen conditions employed. With more or less rapid supply of oxygen to the roots, and possibly with other solution and non-solution conditions than those here giving best growth, it is of course possible that still better growth might be obtained. No attempt was made to study the influence of oxygen partial concentration in the media used in these experiments.

From the preceding paragraphs it is clear that the solution conditions (salts, salt proportions, total concentration, oxygen partial concentration, as well as the partial concentrations of excreted substances) altered in some unascertained manner from the time the seedlings were placed in the culture bottles to the time of the first renewal of the solution. At the time of renewal the solution conditions were suddenly brought back to the state in which they were at the beginning of the culture. Then alteration began once more and continued for three or four days, when these conditions were again brought back to standard. The standardization of these conditions was subsequently repeated at intervals of three or four days till the end of the culture period.

No attempt was made to determine how the solutions changed between renewals. The line of study here suggested has attracted considerable attention in the past and will surely be continued by plant physiologists, but it has not yet been applied to rice in any thorough manner.

THE NON-SOLUTION CONDITIONS OF THE ENVIRONMENT

By non-solution conditions of the surroundings are here meant all those conditions that may have influenced the growth of these plants, excepting the conditions that are determined directly by the salts, salt proportions, and total concentration of each culture solution. These non-solution conditions of the evironment were

practically the same for all the cultures of any single series, and they were the same for all series that were carried out simultaneously (see dates given in Table 3). To approach practical uniformity among simultaneous cultures, the culture bottles were placed on motor-driven rotating tables such as were used by Shive (1915). The tables stood in one of the greenhouse rooms, being located as those of Shive had been.

During the course of each culture series records of the air temperature in the greenhouse in which the cultures were carried out were obtained by means of a thermograph in the shade, under one of the rotating tables. Daily records of the evaporating power of the air and of radiation (sunshine) were also made, by means of the radio-atmometer (white and black spheres).[26] These records will serve to show, in a general way, the temperature, the moisture, and the total radiation conditions for each experiment series.

PLANT RECORDS

For some cultures the volume of solution remaining in the culture bottle at each solution renewal was measured, and the volume absorbed by the plants for the preceding period was determined. Finally, from these determinations was obtained the total volume of solution absorbed by the plants for the entire three-week period. This may be taken as practically the same as the total volume of water transpired during the period.

At the end of the experiment period each set of cultures was separated into three groups representing good, medium, and poor growth, respectively, and a representative from each group was photographed. Notes on the appearance of the plants and the mean lengths of tops and of roots were approximately determined. The plants were then removed from the stopper, the remnant of the seed was discarded in each case, and the tops were severed from the roots at the point of attachment to the seed. The dry weights of tops and of roots (the six plants in each culture being treated as a whole) were then obtained in the usual way, the drying being done finally at a temperature of about 105°C.

In some cases the green weights of tops were approximately determined, to obtain information on the water content, etc. The severed tops from each culture were immediately transferred into a test tube which was then closed and stored in a refrigerator until weighing could be accomplished, which in this case

[26] Livingston, B. E., Atmometry and the porous cup atmometer, Plant World 18 (1915) 21–30, 51–74, 95–111, 143–149.

was within twenty-four hours. The tube with its contents was weighed, the plant material was removed (and preserved for the dry-weight determination), and the tube was finally weighed dry. From the data thus obtained the green weight and the water content of the tops were determined, the latter being finally expressed as percentage on the basis of green weights.

RESULTS

AËRIAL CONDITIONS OF THE EXPERIMENT SERIES

Before proceeding to the presentation of the results obtained from the plants it will be well to present, once for all, the data that characterize the aërial conditions for the various experiment

TABLE 4.—*Maximum and minimum temperatures and average daily atmometric and radio-atmometric indices for the different experiment periods.*

Series No.	Experiment period (1918). Beginning.		Ending.		Days.	Air temperature. Maximum.	Minimum.	Average daily atmometric index.[a] Maximum.	Minimum.	Average.	Average daily radio-atmometric index.[a] Maximum.	Minimum.	Average.
						°C	°C	cc.	cc.	cc.	cc.	cc.	cc.
4	February	22	March	14	20	33	9	26.9	12.0	20.2	......	......	......
10													
11	March	11	April	5	25	32.2	8.5	33.9	11.1	23.0	......	......	......
12													
13													
1													
2													
5	March	21	April	11	21	32.2	8.0	27.2	11.1	22.3	......	......	......
7													
8													
3													
6	March	24	April	11	18	32.2	8.0	26.8	11.1	22.2	......	......	......
9													
15													
18	May	24	June	14	21	33.0	1.40	......	......	......	......	......	......
21													
14													
16													
19	June	19	July	9	20	35.0	14.0	27.6	6.3	18.1	2.7	.77	1.8
20													
23													
25	August	3	August	23	20	39.0	15.0	30.4	14.3	18.2	3.2	.63	1.9
27													
24													
26	September	9	September	29	20	30.0	9.0	19.7	6.2	12.0	2.1	.54	1.3
28													

[a] The atmometric index is the daily rate of water loss from standard white spherical porous-cup atmometer. The radio-atmometric index is the daily excess of water loss from standard black spherical atmometer, above that from the white.

series as far as these were obtained.   This information will aid in making comparisons with similar series that have been carried out by other students or that may be carried out in the future, and will also furnish some fragmentary evidence regarding the sort of aërial conditions that prevail in a greenhouse at Baltimore for the seasons considered.   They are set forth in Table 4.

<div align="center">PLANT RECORDS</div>

The numerical plant data derived from these experiments and to be considered below include the following values, though these values were not all obtained for all cultures or for all series:

(1) Dry yield of tops (six plants).
(2) Dry yield of roots (six plants).
(3) Green weight of tops (six plants) and percentage of water content.
(4) Total absorption (six plants).
(5) Water requirement per unit of dry weight.
(6) Approximate length of tops (mean for six plants).
(7) Approximate length of roots (mean for six plants).

The results will be presented below, the three types of solution being considered in order.

<div align="center">THREE-SALT TYPE I (MONOPOTASSIUM PHOSPHATE, CALCIUM NITRATE, MAGNESIUM SULPHATE)</div>

Numerical data were not generally obtained for the rice plants grown in the 3-salt solutions of type I, since it was evident throughout these series that none of the cultures were producing what might be called good growth; all exhibited much poorer growth than was obtained from the better solutions of the two types with ammonium.   As to the comparative physiological values of the fifteen different sets of salt proportions tested, solutions R1S1, R2S1, R3S1, R4S1, and R5S1 always appeared to be nearly alike and much better than any of the others, while solutions R1S3, R1S4, R1S5, and R2S4 were nearly alike and always belonged to the poor group.   These statements refer to all the different total concentrations tested.   The comparative values of the fifteen different sets of salt proportions may be represented by the length values for tops, which were obtained for series 4.   The relative quantities standing for these top values are shown in the diagram of fig. 1, for which the largest value (actually 20 centimeters) is considered as unity.   It is seen at once that the region nearest the left margin of this diagram represents the best-balanced sets of salt proportions, while the region of the right apex represents the poorest sets.

The solution represented by the right apex itself (R1S5) is by far the poorest of the series, giving tops only 62.5 per cent as long as those given by solution R4S1, which is the best of the series. This means that solutions having relatively low partial concentrations of the calcium salt are the best. None of the five best sets of salt proportions has over one-seventh of its molecular total made up of calcium nitrate. The three solutions having four-sevenths or five-sevenths made up of calcium nitrate (which are also characterized by low partial concentration of magnesium sulphate) all lie in the poor group.

The root lengths were also obtained for series 4, and they are shown by their relative values on the diagram of fig. 2, but they bring out no clear generalization. In this case unity (1.00) represents an actual value of 14.5 centimeters.

Although the 3-salt solutions of the present study are planned by volume-molecular rather than by osmotic salt proportions (the latter having been used by Shive), yet it will be of interest to compare the generalization stated above for these young rice plants, with the outcome of Shive's series for wheat (1915), buckwheat (1917), and soy bean.[27]

The triangular diagrams in question are shown in fig. 3, in which the diagram of fig. 1 is repeated for the sake of comparison. Considering the main regions of good and poor growth, as marked on these diagrams, for wheat it appears that the best sets of salt proportions are near the center of the triangle, with the three salts in somewhat nearly equal proportions, while the poorest sets have very low partial concentrations of monopotassium phosphate and calcium nitrate and very high partial concentrations of magnesium sulphate. For buckwheat low or medium partial concentrations of calcium nitrate together with medium partial concentrations of monopotassium phosphate represent the best sets of proportions, while the poorest sets have low partial concentrations of magnesium sulphate together with medium and high concentrations of monopotassium phosphate. For soy bean [these data have been derived from Shive's table of results given (1918) on page 109] it appears that low partial concentrations of monopotassium phosphate clearly limit the region of good balance, while high ones represent poor balance. It is remarkable that the diagram for soy bean is very similar to that for rice, except that good physiological balance for soy bean seems to require a very low supply of monopotassium phos-

[27] Shive, John W., Toxicity of monobasic phosphates towards soy-beans grown in soil- and solution-cultures, Soils Sci. 5 (1918) 87–122.

phate, while calcium nitrate seems to constitute a corresponding
limit for rice; if the soy-bean diagram were rotated a third of
a revolution in the clockwise direction it would correspond very
closely to the rice diagram.

The points just brought out emphasize what seems likely to
be a very important general principle in the science of plant
nutrition; namely, that different plant forms may require entirely
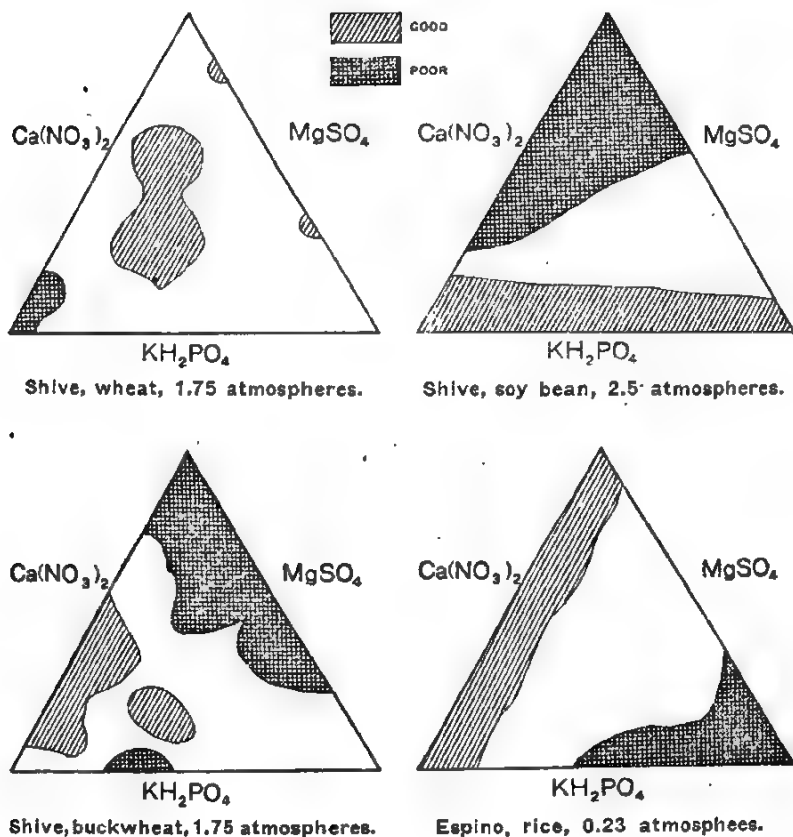
FIG. 8. Good and poor sets of salt proportions for four plant forms.

different sets of salt proportions for good physiological balance.
The comparison just made involves only four plants and no two
show a tendency to agree as to the solution characteristics that
give best growth. It is of course to be expected that, as the
salt requirements of other plants are made known, and as those
of the plants here considered become better understood, it will
be found that there are a number of types of salt requirement,

among which the different plant forms will be found to be distributed. It should be emphasized that the data for the four plants thus far studied indicate no solution as well balanced for all, although those with lowest partial concentrations of both monopotassium phosphate and calcium nitrate should be well balanced for both soy bean and rice.

Aside from the question of salt proportions, it is to be noted that Shive's best solutions for wheat and buckwheat have osmotic values of 1.75 atmospheres, and that the best solution he records for soy bean has an osmotic value of 2.5 atmospheres; while the best total concentration for rice, with this type of solution, proved to be about 0.2 atmosphere. In connection with all these considerations it is to be remembered that none of these 3-salt solutions gave really good growth to the young rice plants; what is termed "good" on the lowest diagram of fig. 3 is only relatively good—that is, the best obtained with this solution type. It is thus suggested that the best solution for these rice plants will be found to have a very low total concentration, as compared with the best solutions for wheat, buckwheat, and soy bean. This is borne out by the findings to be reported in the following sections of this paper.

It seems, therefore, that the total concentration best suited to the growth of a given plant is determined not only by the salts and salt proportions but also by the kind of plant considered; also probably by the developmental stage of the plant and by the non-solution conditions of the environment. Different plant forms show different requirements with respect to the total concentration as well as with regard to salt proportions.

The general appearance of the rice plantlets after growing three weeks in the best of these 3-salt solutions is shown by the photograph, Plate 1, fig. 6.

FOUR-SALT TYPE A (MONOPOTASSIUM PHOSPHATE, CALCIUM NITRATE, MAGNESIUM SULPHATE, AMMONIUM SULPHATE)

Introductory.—The results obtained with the four-salt solution type A [29] refer to nine different experimental series (series 14 to 22 inclusive, see Table 3) and to six different total concentrations. The numerical results will be presented after values, but the general appearance of the plants has been considered.

General appearance.—After five or six days in the culture

---

[29] A single set of salt proportions of this type of solution was used by Wolkoff; see Wolkoff, M. I., Effect of ammonium sulphate in nutrient solution on the growth of soy beans in sand cultures, Soil Sci. **5** (1918) 123–150.

solutions differences in the appearance of the plants generally began to be manifest and these differences became more striking as the cultures became older. With higher total concentrations these differences became pronounced sooner than with lower total concentrations. All of the cultures of series 14 to 22 inclusive gave better plants than were obtained in distilled-water cultures simultaneously carried out; the lowest total concentration tried (series 14, 0.0008 gram-molecule per liter, or 0.04 atmosphere) gave better growth in all of its salt proportions than did distilled water. Of the six total concentrations tested, it was generally true that the plants grew faster at first in the weaker solutions, but after about ten days of growth some of the cultures having the second or third total concentration (series 15 and 16, 0.0016 gram-molecule or 0.08 atmosphere, and series 17, 18, and 19, 0.0038 gram-molecule per liter, or 0.2 atmosphere) showed the most rapid growth.

Most of the cultures with the three weaker total concentrations gave good growth, and the best plants of these series were much better in appearance than were the best ones obtained in any of the 3-salt series with rice. There was generally some drying of the tips of the leaves, especially in the first half of the culture period, and this feature was developed more strongly as the total concentration was higher; but it appeared not to be related to salt proportions, for it was about the same for all. While the dead regions of the leaf tips were only about 0.5 centimeter long with the lowest total concentration used, they were two or three times as long with the fourth of the total concentrations (series 20, 0.0077 gram-molecule per liter, or 0.40 atmosphere). The best cultures of series 14 to 20 (with the four lower concentrations) showed good color and the plants were apparently normal in every way.

The highest two total concentrations (series 21 and 22, 0.0192 and 0.0384 gram-molecule per liter, or 1 and 2 atmospheres, respectively) gave poor growth with all salt proportions, the plants appearing markedly stunted, and the leaves drying badly at the tips or even so far as to affect nearly the whole blade. Chlorotic leaves were common with these two stronger total concentrations. For these two series no quantitative plant measurements were made, and they will not be considered in the sections that follow.

In connection with this observation that the highest two concentrations tested showed no sets of salt proportions at all suited to the growth of these plants, it is of interest to emphasize the

fact·that the lower one of these two highest total concentrations (series 21, 0.0192 gram-molecule per liter, or 1 atmosphere) was much less concentrated than Shive's best solution for young wheat plants. Whatever may be the details in this connection, it is safe to say that Shive's wheat grew excellently in solutions with osmotic values of 1.75 atmospheres, or even higher, while the rice of the present studies failed to develop even fairly well, with any set of salt proportions, if the osmotic value was greater than about 0.4 atmosphere. Turning to the other plants that have been studied in a systematic way by Shive (1917), by Shive and Martin,[29] and by Shive (soybeans, 1918), it will be seen that buckwheat gave about twice as much in dry yields of tops with the best sets of salt proportions for a total concentration of 1.75 atmospheres as it did with the best ones for a concentration of 0.1 or 4 atmospheres; so that it is evident that rice does not require nearly so high a total concentration for its best growth while young as does buckwheat. Also, Shive obtained excellent growth for soy beans with a total concentration value of 2.5 atmospheres, which indicates that this plant thrives best for the first few weeks in solutions much more concentrated than can well be borne by young rice plants. It may safely be said that rice differs remarkably from wheat, buckwheat, and soy bean, in that, in the case of these three plants, the total concentrations of the nutrient salt mixtures that show best growth in the young ones (when the salt proportions are properly arranged) have osmotic values well above 1 atmosphere, while this value is only about 0.5 atmosphere, or even lower, in the case of rice.

These considerations regarding the comparative ability of rice, wheat, buckwheat, and soy bean to withstand high total concentration of the culture solution, providing the salt proportions are properly arranged, will be still further emphasized when the quantitative data of the present studies are considered.

Throughout these series with the 4-salt solution type A, the yellowing of the leaves was generally more intense for the smaller plants; that is, chlorosis and stunted growth appeared to be controlled by the same sets of conditions. The more pronounced differences in size were paralleled by similar differences in dry yield.

[29] Shive, John W., and Martin, William H., A comparative study of salt requirements for young and for mature buckwheat plants in solution cultures, Journ. Agr. Res. 14 (1918) 151–175. Idem, A comparison of salt requirements for young and for mature buckwheat plants in water cultures and sand cultures, Am. Journ. Bot. 5 (1918) 186–191.

There was generally good agreement in the appearance of the six plants of any culture. Occasionally a seedling died, but this was rare. For such cases the quantitative data have been computed to represent six plants, although actually based on only five.

As to the different sets of salt proportions, the appearance of the plants became progressively poorer (especially with reference to chlorosis and size) with higher relative partial concentrations of monopotassium phosphate; that is, as the top apex of the tetrahedral diagram is approached, the plants are shown to have become more and more stunted and chlorotic. The best-appearing plants represent sets of salt proportions given in the lowest or the lowest two triangles of the diagram and the poorest plants represent the sets at or near the top apex.

Dry yield of tops.—The dry yield of tops from series 14 to 20 is shown in Table 5, all values being expressed in terms of the corresponding value for culture T1R1S1 of the same series. The actual value (fraction of a gram) for the last-named culture is given in parentheses beneath the value 1.00, in each case. Values marked H belong to the highest seven values obtained in the given series, those marked L belong to the lowest seven. These two groups of seven values (there are generally more than seven cultures included, on account of like values from two or more of them) will be called the high and the low groups. The date of beginning of each series is given beneath the series number.

Inspection of Table 5 brings out the fact that, where repetitions were made there are frequent discrepancies, a given solution giving a high relative value for one trial and a medium or low value for another trial. These discrepancies are attributable to unknown conditions (perhaps largely to the non-solution conditions called climatic). It will be remembered that these different trials were made at different seasons of the year, as indicated by the dates. It has been emphasized by other writers that the relative value of any solution must be expected to be different for different sets of non-solution conditions, providing, of course, that the latter differences are large enough to be effective. Whatever may have been the conditional differences that were at work in these cases of discrepancy, it is clear that comparisons between the physiological properties of the solutions here considered (as to whether they gave high, medium, or low yields of tops) must be made only in a broad and general way. It is to be supposed that, had series 14 and

171114——4

20 been repeated, they also would have shown discrepancies similar to the ones shown for series 15 and 16 and for series 17 to 19.   It is obvious that better control of non-solution conditions must be employed before such comparisons as the ones

TABE 5.—*Relative dry yields of tops (six plants), from series with 4-salt solution type A.*

[The value for culture T1R1S1 is always taken as unity and the others are expressed in terms of this. The actual value (grams) for this culture is given in parentheses below the assumed value of unity, in each case.]

Solution No.	Total concentration 0.0008 gram-molecule per liter, or 0.04 atmosphere.	Total concentration 0.0016 gram-molecule per liter, or 0.08 atmosphere.		Total concentration 0.0038 gram-molecule per liter, or 0.2 atmosphere.			Total concentration 0.0077 gram-molecule per liter, or 0.4 atmosphere.
	Series 14, June 19.	Series 15, May 24.	Series 16, June 19.	Series 17, May 1.	Series 18, May 24.	Series 19, June 19.	Series 20, June 19.
T1R1S1	1.00	H 1.00	H 1.00	H 1.00	H 1.00	H 1.00	H 1.00
	(0.198)	(0.416)	(0.239)	(0.354)	(0.420)	(0.243)	(0.226)
S2	0.98	H 0.98	H 0.98	H 1.02	H 0.97	0.86	0.73
S3	0.99	H 0.96	H 0.96	0.85	H 0.94	0.84	0.73
S4	0.74 L	0.90	0.95	H 0.89	H 0.91	0.79	0.69
S5	0.83 L	0.81 L	0.85	0.74	0.80	0.68 L	0.64
R2S1	1.04	H 0.98	H 1.02	H 0.96	H 0.96	H 0.91	H 0.82
S2	H 1.16	H 0.94	0.94	0.87	H 1.00	0.84	H 0.88
S3	H 1.09	H 0.92	0.87	H 0.93	0.77	0.82	0.71
S4	H 1.08	0.88	0.80 L	H 0.92	0.79	0.83	0.65
R3S1	H 1.08	H 0.93	H 1.00	0.82	0.82	0.89	H 1.04
S2	1.08	H 0.93	H 0.99	0.80	H 0.95	H 0.95	H 0.91
S3	0.94	0.80 L	0.87	0.74	0.88	H 0.95	0.71
R4S1	1.00	0.88	0.92	H 0.95	0.90	H 1.04	H 0.93
S2	H 1.14	0.80 L	0.87	H 0.92	H 0.94	H 0.92	0.74
R5S1	0.94	0.79 L	0.93	0.80	0.81	0.76	0.68
T2R1S1	1.01	H 0.97	0.92	0.81	H 0.96	H 0.97	H 0.85
S2	0.90 L	0.91	0.85	0.69	H 0.95	0.82	0.73
S3	0.86 L	0.86	0.83 L	0.77	0.74 L	0.85	0.65
S4	0.78 L	0.85	0.80 L	0.62 L	0.67 L	0.51 L	0.58 L
R2S1	0.93	0.89	H 0.96	0.84	0.79	0.87	0.63
S2	H 1.11	0.88	H 1.17	0.65 L	0.77	H 0.99	0.73
S3	0.92 L	0.84 L	0.68 L	0.68	0.73 L	0.72 L	0.61 L
R3S1	H 1.16	0.92	0.89	0.69	0.89	0.72 L	0.77
S2	H 1.08	0.87	0.91	0.66 L	0.87	0.75	0.72
R4S1	1.08	0.87	0.92	0.72	H 0.92	0.86	0.56 L
T3R1S1	1.02	0.90	0.90	0.75	0.79	0.47 L	0.70
S2	1.04	0.75 L	0.85	0.62 L	0.67 L	0.71 L	0.69
S3	0.86 L	0.80 L	0.74 L	0.54 L	0.67 L	0.58 L	0.35 L
R2S1	H 1.14	0.82 L	H 1.20	0.71	0.86	0.73 L	0.75
S2	1.03	0.87	0.72 L	0.62 L	0.88	0.71 L	0.53 L
R3S1	H 1.21	H 0.96	0.92	0.66 L	0.71 L	0.73 L	0.58 L
T4R1S1	0.94	0.87	0.72 L	0.61 L	0.70 L	0.79	0.60 L
S2	0.88 L	0.83 L	0.69 L	0.45 L	0.64 L	0.51 L	0.58 L
R2S1	H 1.10	0.87	0.81 L	0.56 L	0.76 L	0.75	0.53 L
T5R1S1	H 1.09	0.88	0.80 L	0.54 L	0.74 L	0 58 L	0.57 L

here made may be interpreted in any great degree of detail. Until such controls (especially of air and light conditions) become available, all that can be done is to make the survey for such problems as this rather superficial, to discuss the more- and the less-promising solutions for the uncertain range in the complex of non-solution conditions with which the whole investigation deals. This will be attempted in the present case, and the generalizations that are presented below are to be regarded as only tentatively established; they are meant to apply to such non-solution conditional complexes as were met with in the greenhouse here used, between May 1 and July 9.

It is seen from Table 5 that no set of salt proportions falls in the high group (H) for all series and that only two sets (T3R1S3 and T4R1S2) fall in the low group (L) for all series. Furthermore, no set of proportions falls in the medium group (unmarked in the table) for all series. Inspection of the actual top yields (from which the relative values of Table 5 have been computed) leads to the conclusion that the solutions of series 14 (the lowest total concentration dealt with) are in general too dilute to give the best growth of these plantlets, and, similarly, that those of series 20 (the highest total concentration studied) are too concentrated. This statement is supported by the data of Table 6, which shows the ranges of the actual top-yield values for the high and low groups, for the four series carried out simultaneously beginning June 19. A similar summary of the ranges for root-yield values is given in the same table.

TABLE 6.—*Highest and lowest yields of tops and of roots (milligrams) in the high and in the low groups for the four series carried out simultaneously beginning June 19.*

		Series 14 (lowest total concentration).		Series 16 (low-medium total concentration).		Series 19 (high-medium total concentration).		Series 20 (highest total concentration).	
		Highest.	Lowest.	Highest.	Lowest.	Highest.	Lowest.	Highest.	Lowest.
Tops....	High group...	240	214	287	235	253	224	236	185
Do....	Low group...	184	154	192	163	176	115	138	80
Roots...	High group...	85	72	78	72	74	64	82	50
Do....	Low group...	65	54	62	52	53	42	45	36

From the upper part of Table 6 it appears that the maximum top yields from series 14 and 20 are both lower than either of the corresponding maxima for the two remaining series, and that the minimum top yields for the high group for series 14

and 20 are likewise lower than the corresponding minima for the two other series. For the low group the evidence is not so clear, but both minimum and maximum for series 16 are higher than the corresponding minima and maxima for series 14 and 20.

On the whole, it seems safe to conclude that the most promising solution for these young rice plants is to be looked for among solutions having total concentrations higher than the lowest and lower than the highest concentration here considered. For this reason attention will be mainly turned toward the series employing the two medium total concentrations (series 15 and 16, and series 17 to 19).

Before leaving the general subject of the comparison of the four different total concentrations, however, it may be remarked that both high and low yields are shown for all the triangles of the tetrahedral diagram (except the top one) for the lowest total concentration, but that the two groups become more and more sharply segregated with higher total concentrations, so that with the highest concentration (series 20) all the high values but one (T2R1S1, which has a comparatively low value for the high group) occur in the lowest triangle (T1), while no low values at all are shown for that triangle. This progressive segregation of the high values toward the lowest triangle of the diagram, with progressively higher total concentrations, may be considered to mean that the higher the total concentration the smaller must be the relative partial pressure of monopotassium phosphate, if excellent growth is to be expected. No segregation of this sort is apparent for series 14, with the lowest concentration studied, and the distribution of the low and high top-yield values in this series fails to suggest any definite relation between salt proportions and these values. This fact, together with other data for series 14, seem to indicate that the total concentration is here too low to produce the best growth of these plants and to bring out their salt relations as has been mentioned. Omitting this series, we may observe that just two solutions (T1R1S1 and T1R2S1) gave high values in all the remaining series, so that these two solutions appear, on the whole, to be most nearly balanced for these plants, for the whole range of total concentrations dealt with.

Turning now to a special study of the solutions having medium total concentration (series 15 to 19), the upper part of Table 6 indicates that the low-medium was generally better suited to the production of top yields than was the high-medium total con-

centration.   Another comparison between these two total con-
centrations is possible, however, from the data of series 15 and
18, carried out simultaneously in the period beginning May 24,
and data for this comparison are given in Table 7, which is
planned like Table 6.   For ready comparison, the data for series
16 and 19 are here repeated from the other table.   For each
series of each period the higher of the two comparable values is
shown in bold-face type.

TABLE 7.—*Highest and lowest yields of tops and of roots (milligrams) in
the high and in the low groups for the low-medium and high-medium
total concentrations (series 15, 16, 18, and 19).*

		Period beginning May 24.				Period beginning June 19.			
		Series 15 (low-medium total concentration).		Series 18 (high-medium total concentration).		Series 16 (low-medium total concentration).		Series 19 (high-medium total concentration).	
		Highest.	Lowest.	Highest.	Lowest.	Highest.	Lowest.	Highest.	Lowest.
Tops....	High group__	416	**389**	**420**	**394**	**287**	**235**	253	224
Do.....	Low group___	**345**	**313**	309	267	**192**	**163**	176	115
Roots..	High group__	**128**	**118**	120	108	**78**	**72**	74	64
Do.....	Low group....	**98**	71	90	**75**	**62**	**52**	53	42

It appears from the upper part of Table 7 that, in three cases
out of four, both maximum and minimum top values for the
high group, and also for the low group, are greater for the low-
medium total concentration than for the high-medium, while
preference is suggested for the high-medium total concentration
in the fourth case, that of May 24, of the high group.   In this
case the differences are much smaller than in the others and
they are too slight to be considered as significant (420 milli-
grams is not significantly greater than 416, nor 394 than 389).
It may be added here that the evidence from root yields in the
lower part of Table 7 points in the same direction, the agreement
being actually better here than in the case of top yields, for the
only comparison that gives preference to the high-medium total
concentration on this basis is that between the two minima for
the low group, 75 and 71 milligrams.

From these and other considerations it seems clear that the
low-medium total concentration (0.0016 gram-molecule per liter,
or 0.08 atmosphere) is to be regarded as generally more prom-
ising, for these plants and these non-solution conditions and
for this 4-salt type of medium, than is the high-medium total
concentration (0.0038 gram-molecule per liter, or 0.2 atmos-
phere).   The differences are not generally relatively very great,

however, and it may be safer to conclude from the limited data (and considering the discrepancies shown by the repetitions) that the most promising total concentration lies within the range between these two, perhaps nearer to the lower limit than the upper.

Reverting to Table 5 and taking up now the comparative physiological values for top yield of the various sets of salt proportions for the two medium total concentrations, it will be instructive to study the agreements and disagreements between

TABLE 8.—*Showing symbols for top and root yield of series 15 to 19.*

Solution No.	Top yields.		Root yields.	
	Low-medium total concentration. Series 15, 16.	High-medium total concentration. Series 17-19.	Low-medium total concentration. Series 15, 16.	High-medium total concentration. Series 17-19.
T1R1S1	H	H	H	H
S2	H	Hm	H	H
S3	H	Mh	H	H
S4	M	Hm	M	Mh
S5	LM	Ml	L	Ml
R2S1	H	H	H	H
S2	HM	Mh	H	Hm
S3	HM	Mh	M	Mh
S4	LM	Mh	L	HML
R3S1	H	M	HM	Mh
S2	HL	Hm	LM	Mh
S3	LM	Mh	L	HML
R4S1	M	Hm	L	Mh
S2	LM	H	L	H
R5S1	LM	M	L	M
T2R1S1	HM	Hm	H	H
S2	M	Mh	H	Hm
S3	LM	Ml	M	M
S4	LM	L	LM	L
R2S1	HM	M	HM	Hm
S2	HM	HML	H	Hm
S3	L	Lm	L	M
R3S1	M	Ml	HL	HML
S2	M	Ml	L	Ml
R4S1	M	Mh	HL	Mh
T3R1S1	M	Ml	H	Mh
S2	LM	L	M	Ml
S3	L	L	LM	L
R2S1	LH	Ml	HM	M
S2	LM	Lm	M	Mh
R3S1	HM	L	HM	Lm
T4R1S1	LM	Lm	HL	Lm
S2	L	L	LM	L
R2S1	LM	Lm	HM	Ml
T5R1S1	LM	L	HM	L

the two low-medium series and between the three high-medium series, also between the low-medium and the high-medium concentrations, as indicated by the groups (high, medium, and low) in which the various sets of salt proportions fall.

These agreements and disagreements are set forth in Table 8, which also includes the corresponding data for root yields. In this table the letters H, M, and L are employed to show in which group any given set of salt proportions fell for each trial. In the case of the lower of these two medium total concentrations there were two trials, and disagreement between the two is shown by the use of both letters (thus, HM denotes that one trial showed the solution in question as in the high group, while the other trial showed it as in the medium group). In the case of the higher total concentration there were three trials. When all were different in their indications all three letters are given in the table; when two of them agreed but the third was different, only two letters appear, but one is lower-case, to denote that only one trial is thus referred to. Thus, if the three trials call for L, L, and M respectively, the designation is Lm, etc.

Table 8 shows that solutions T1R1S1, T1R1S2, and T1R2S1 agree in giving high top yields, while solutions T2R2S3, T3R1S3, and T4R1S2 agree in giving low top yields, for both total concentrations. The other solutions show medium top yields or are more or less questionable, as far as the data go. It seems safe to conclude that the first three solutions just named may be expected to produce excellent top growth for this sort of plants, when the total concentration is between 0.0016 and 0.0038 gram-molecule per liter (0.08–0.2 atmosphere), while the last three mentioned may be taken as representing the poorly balanced sets of salt proportions of these series. The distribution of these and the other solutions on the tetrahedral diagram, together with the chemical interpretation of this, will be deferred till after the root yields have been presented.

Dry yields of roots.—The relative dry yields of roots from series 14 to 20 are presented in Table 9, in a manner quite like that followed for the top yields in Table 5.

From Table 9 it appears that disagreements are fully as frequent among the root yields as among those of tops, and the remarks made concerning the discrepancies in the other case will apply here also.

It appears that solution T1R1S1 and T2R1S1 agreed in giving high root yields for all series, and that no one of the thirty-five sets of salt proportions gave low root yields for all series.

TABLE 9.—*Roots, relative dry yields (six plants), from series with 4-salt solution type A.*

[The value for culture T1R1S1 is always taken as unity and the others are expressed in terms of this. The actual value (grams) for this culture is given in parentheses below the assumed value of unity, in each case.]

Solution. No.	0.0008 gram molecule per liter, or 0.04 atmosphere.	0.0016 gram-molecule per liter, or 0.08 atmosphere.		0.0038 gram-molecule per liter, or 0.2 atmosphere.			0.0077 gram-molecule per liter, or 0.4 atmosphere.
	Series 14, June 19.	Series 15, May 24.	Series 16, June 19.	Series 17, May 1.	Series 18, May 24.	Series 19, June 19.	Series 20, June 19.
T1R1S1	H1.00 (0.185)	H1.00 (0.128)	H1.00 (0.078)	H1.00 (0.098)	H1.00 (0.120)	H1.00 (0.074)	H1.00 (0.068)
S2	0.81	H0.98	H0.94	H1.02	H0.98	H0.92	H0.75
S3	0.79	H0.94	H0.90	H0.92	H0.90	H0.92	0.73
S4	0.71	0.89	0.85	H0.95	0.87	0.76	0.68
S5	0.64L	0.77L	0.80L	0.78	0.78	0.68L	0.69
R2S1	0.79	H0.96	H1.00	H1.01	H0.96	H0.91	H0.75
S2	H0.85	H0.91	H0.90	0.89	H0.96	H0.85	H1.20
S3	0.84	0.84	0.86	H0.95	0.78	0.84	H0.75
S4	0.76	0.63L	0.80L	H0.92	0.75L	0.81	0.71
R3S1	H0.85	0.79	H0.91	0.84	0.88	H0.85	H0.87
S2	0.67L	0.67L	0.85	0.87	H0.99	H0.93	H0.81
S3	0.78	0.64L	0.71L	0.67L	0.88	H0.92	H0.74
R4S1	0.64L	0.61L	0.74L	H0.97	0.80	0.81	0.71
S2	0.74L	0.56L	0.67L	H0.92	H0.92	H0.91	0.65L
R5S1	0.64L	0.56L	0.69L	0.84	0.63	0.76	0.56L
T2R1S1	H0.91	H0.95	H0.94	H0.95	H0.95	H0.95	H0.85
S2	0.71L	H0.92	H0.91	0.90	H0.92	H0.93	H0.75
S3	0.66L	0.90	0.87	0.89	0.80	0.84	0.73
S4	0.71L	0.81	0.80L	0.71L	0.68L	0.64	0.71
R2S1	0.68L	0.83	H0.90	H0.95	0.84	H0.89	0.66L
S2	0.74L	H0.93	H0.92	0.71L	0.82	H0.95	H0.74
S3	0.73L	0.77L	0.74L	0.83	0.80	0.78	H0.75
R3S1	0.80	H0.92	0.77L	H0.91	0.85	0.72	0.66L
S2	0.77	0.67L	0.74L	0.90	0.73L	0.87	0.72
R4S1	0.78	H0.91	0.77L	0.87	0.85	H0.95	0.53L
T3R1S1	H0.94	H0.98	H0.95	0.74	H0.90	0.76	H0.75
S2	H0.86	0.81	0.87	0.72L	0.78	0.73	0.69
S3	0.80	0.78L	0.85	0.68L	0.72L	0.69L	0.53L
R2S1	H0.94	0.88	H0.97	0.86	0.85	0.81	0.69
S2	H0.88	0.84	0.81	0.80	H0.93	0.77	0.63L
R3S1	0.80	H0.96	0.87	0.79	0.71L	0.70L	0.62L
T4R1S1	H0.88	H0.92	0.78L	0.73L	0.76L	0.82	0.65L
S2	0.71L	0.81	0.77L	0.58L	0.67L	0.57L	0.68
R2S1	H0.89	H0.92	0.89	0.67L	0.79	0.81	0.54L
T5R1S1	H1.00	H0.98	0.81	0.51L	0.75L	0.62L	0.66L

The range limits given in the lower part of Table 6 indicate a less marked distinction in favor of the two medium total concentrations (as compared with the lowest and highest, series 14 and 20) than is shown for top yields. Nevertheless, partly because the physiological meaning of the dry yield of roots is

not at all understood and partly because the possible errors in cutting, weighing, etc., are much greater for roots than for tops, the same general plan will here be followed as was resorted to in the case of the top yields. Attention will be mainly restricted to the two medium total concentrations, series 15 and 19.

Before leaving the general subject of total concentration it may be remarked that the low and the high root yields are not in any case as clearly segregated as are the corresponding ones for tops; but, with the higher total concentrations, there is a marked tendency for low values to correspond especially to the third, fourth, and fifth triangles of the tetrahedral diagram; that is, to high relative partial concentrations of monopotassium phosphate. As in the case of top yields, the most certainly well-balanced sets of salt proportions have low relative partial concentrations of this salt.

In connection with Table 7 it has been noted that the limited information at hand appears to indicate that the lower of the two medium total concentrations may be appreciably better for root yields, as well as for top yields, than is the higher. Since the differences are not great, they require no emphasis at this time, however.

The agreements and disagreements between the similar series, with regard to root yields, are given in Table 8, the notation of which has already been explained. Reference to that table brings out the fact that the following five sets of salt proportions agreed in giving high root yields for all five trials: T1R1S1, T1R1S2, T1R1S3, T1R2S1, and T2R1S1. The first two and the fourth one of these have been noted as showing the same outstanding agreement for top yields. None of the solutions show this kind of agreement for low root yields.

TOP AND ROOT YIELDS IN RELATION TO SALT PROPORTIONS

The relations between yield and salt proportions may be brought out best by the use of the tetrahedral diagram. The symbols shown in Table 8, for tops and for roots, and for the low-medium and high-medium total concentrations, are plotted diagramatically in figs. 4 to 7. The only alteration made in entering the letters on the diagrams has been to change HL to M, on the supposition that a solution giving high yield in one trial and low yield in another trial should be represented as belonging to the medium group. The areas of the diagrams representing high yields and those representing low yields are distinguished by shading. In outlining these areas, combinations

of letters—denoting uncertainty in the data—are treated as belonging to the medium group.

It seems undesirable, considering the discrepancies as to details, to attempt to combine these four diagrams into a single one, but the following remarks will draw attention to the main points on which such a combination might be based. We may begin by considering the two total concentrations separately, as to the degree of agreement between the data for tops and those for roots. For the lower of the two medium concentrations
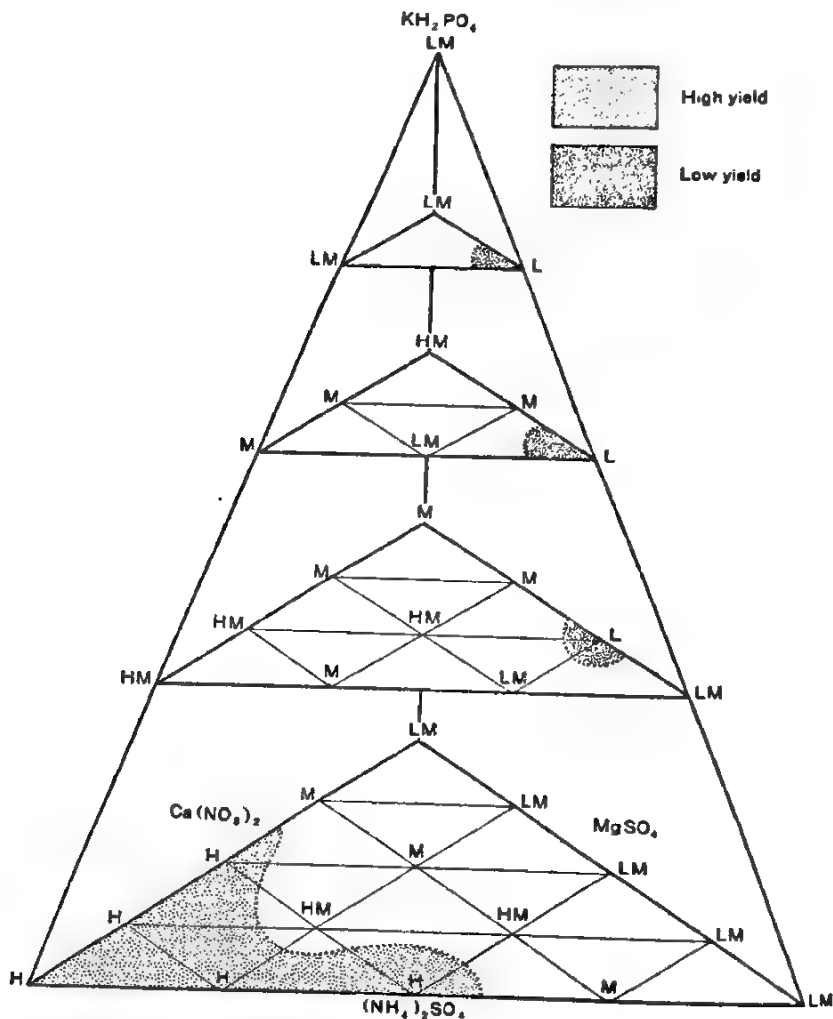

FIG. 4. Top-yield values for the thirty-five different sets of salt proportions, with low-medium total concentration.

considred (0.0016 gram-molecule per liter, or 0.08 atmosphere)
the diagram for top yield (fig. 4) shows five sets of salt propor-
tions as of the high group, all lying in the forward left portion
of the lowest triangle.   No set of proportions in the lowest
triangle is indicated for the low group, but three sets are shown;
one in the second, one in the third, and one in the fourth
triangle, all at or adjacent to the forward right apex.   The
corresponding diagram for root yield (fig. 5) shows about the
same low region in the lowest triangle as is shown for top yield,
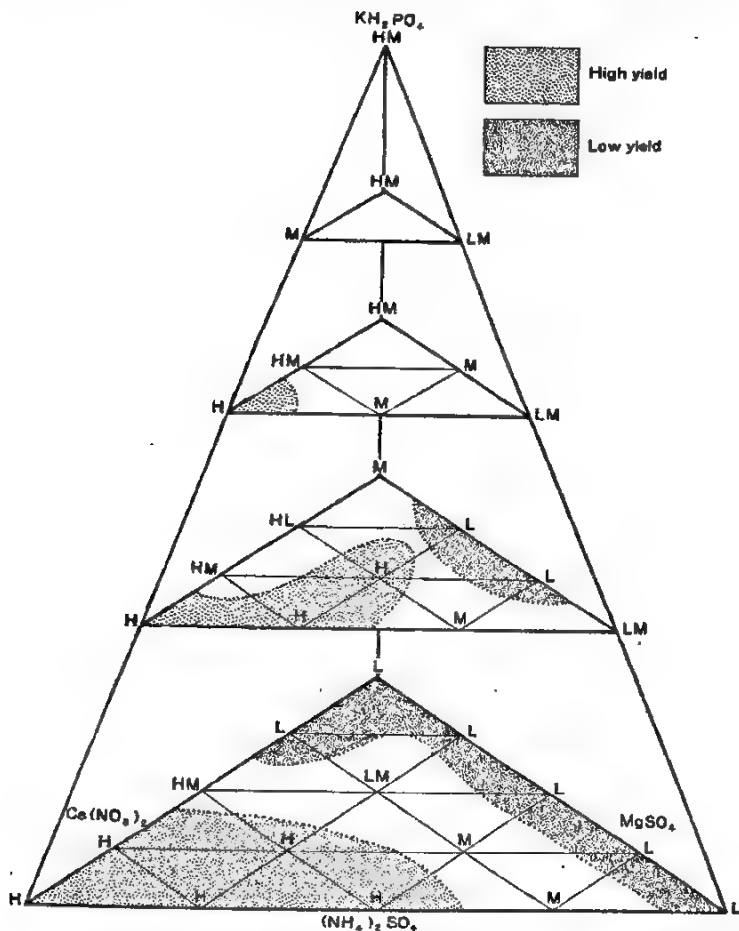but here also there are three high sets of proportions; in the

Fig. 5.   Root-yield values for the thirty-five different sets of salt proportions, with low-
medium total concentration.

middle, in the forward left portion of the second triangle, and at the forward left apex of the third triangle. On this root-yield diagram the low region occupies the whole right margin of the lowest triangle and a portion of the same margin of the second triangle. Just one set of proportions (T2R2S3) is set down as in the low group on both diagrams.

It is especially interesting to note that the yields of tops and of roots agree very well, a feature of these results that is different from what has been indicated for wheat and buckwheat by Shive's work; that writer frequently found low root yields
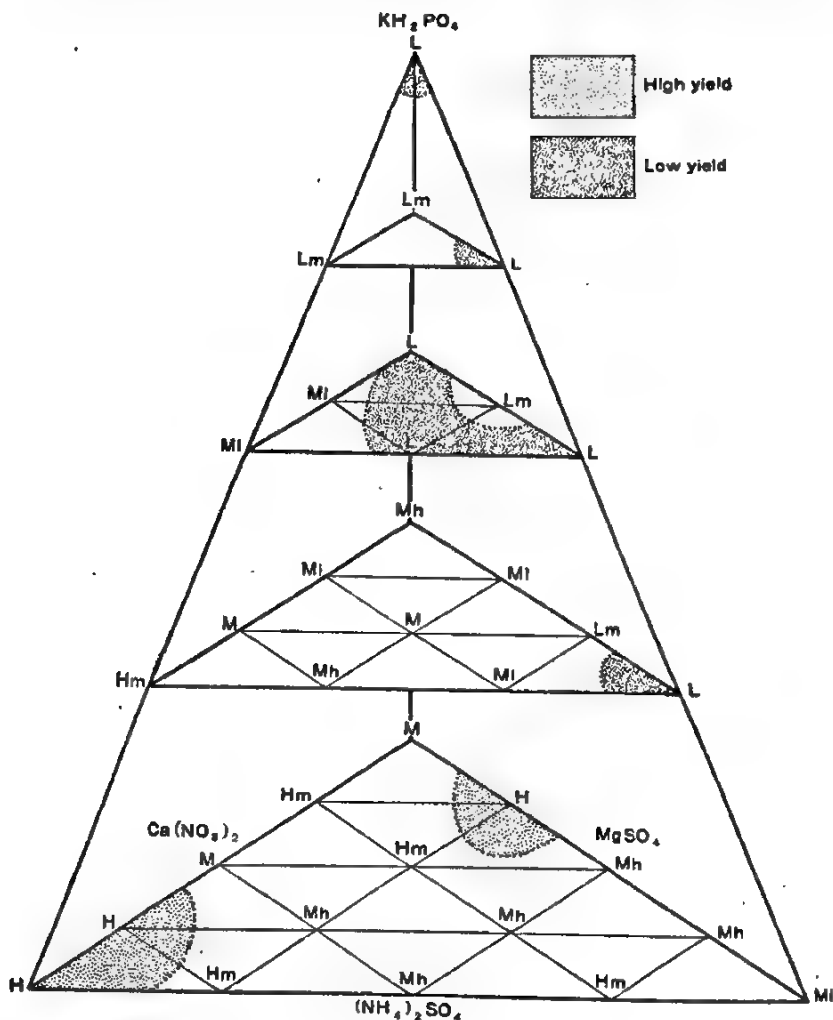

FIG. 6. Top-yield values for the thirty-five different sets of salt proportions, with high-medium total concentration.

accompanying high top yields and, conversely, it appears that the young rice plants generally show parallel, rather than opposite, effects upon top and root production.

Turning to the higher total concentration (0.0038 gram-molecule per liter, or 0.2 atmosphere), only two sets of salt proportions are indicated as of the high group of top yields (fig. 6) in the forward left region of the lowest triangle (the high designation given to solution T1R4S2 appears to be erratic in some way). On this top diagram the low region comprises six sets of salt proportions, lying at the forward right apices of the second,
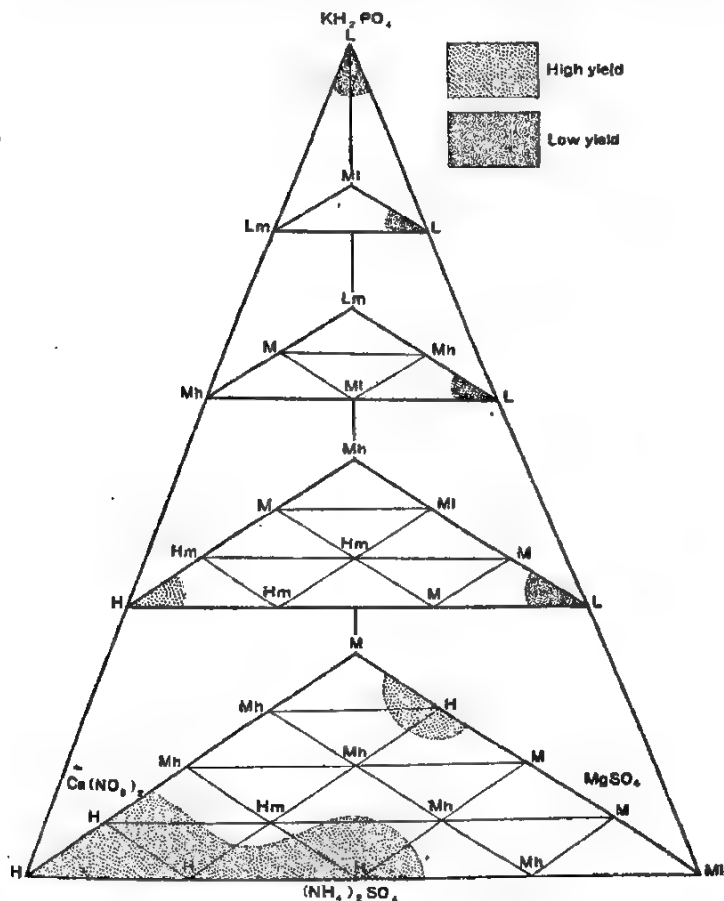

Fig. 7. Root-yield values for the thirty-five different sets of salt proportions, with high-medium total concentration.

third, and fourth triangles and the top apex of the whole tetra-
hedron, and at the rear apex and the forward central region of
the third triangle. The corresponding diagram for root yield
(fig. 7) shows a high region near the forward right apex
of the lowest triangle (much as for the lower total concentration
in regard to both tops and roots) and it agrees with the diagram
for tops in giving a high designation to solution T1R4S2 (which
may be erratic here also). The forward left apex of the second
triangle is also indicated as of the high group, as in the case
of the lower concentration and root yields (fig. 5).

The low region of this root diagram (fig. 7) occupies the
forward right apices of the second, third, and fourth triangles
and the top apex of the tetrahedron as a whole. It differs from
the corresponding top diagram (fig. 6) only in that the low
region is not here extended beyond the forward right apex in
the third triangle.

With the higher of these two total concentrations it is again
clear that top and root yields tend to be parallel, just as with
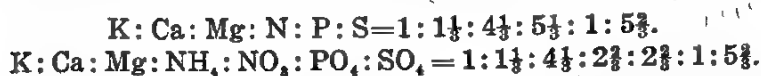the lower total concentration.

Finally, it should be noted that two sets of salt proportions,
T1R1S1 and T1R2S1, are shown as of the high group on all four
diagrams.

Study of the preceding pages and of the diagrams of figs. 4
to 7 leads to the following guarded generalizations. It appears
that solutions T1R1S1, T1R1S2, and T1R2S1 are to be regarded
as having about the best salt proportions for the development
of these plants, with the other conditions involved in these
studies, and it similarly appears that solutions T1R1S5, T2R1S4,
T3R1S3, T4R1S2, and T5R1S1 are to be regarded as very un-
balanced and injurious. Under the given non-solution condi-
tions and with total concentrations lying between 0.0016 and
0.0038 gram-molecule per liter, these plants are found to give
highest yields of both roots and tops when the culture solution
contains relatively large proportions of magnesium sulphate,
and relatively small proportions of the other three salts, them-
selves present in nearly equal proportions. The three solutions
just indicated as best have the salt proportions shown below:

Solution No.	KH_2PO_4.	$(NH_4)_2SO_4$.	$Ca(NO_3)_2$.	$MgSO_4$.
T1R1S1	1	1	1	5
T1R1S2	1	1	2	4
T1R2S1	1	2	1	4

Perhaps a recommendation as to the best set of salt propor-
tions for this solution type for these young rice plants, etc.,
might be obtained by averaging these proportions, thus obtaining
solution T1R1⅛S1⅛, with molecular proportions 1:1⅜:1⅛:4⅛. It
may even be desirable to leave the relative value for magnesium
sulphate as it is in R1S2 and R2S1 and allow the hypotheti-
cally best solution to be T1R1½S1½, with molecular proportions
1:1½:1½:4. Judging from the information at hand, either
T1R1⅛S1⅛ or T1R1½S1½ should give excellent results for both
tops and roots. There seems to be no reason for increasing
the molecular proportional value of monopotassium phosphate
above unity (one-eighth of the total molecular concentration of
all salts taken together) for the hypothetical best set of propor-
tions.

From this generalization it appears that these young rice
plants differ in their physiological salt requirements from many
other plants, notably from wheat, buckwheat, and soy bean, es-
pecially in the fact that the former need relatively a very high
partial concentration of magnesium sulphate, and about equal
and relatively very low partial concentrations of monopotassium
phosphate and calcium nitrate. As has been seen, these rice
plants are also peculiar in that they cannot develop satisfactorily
when supplied with monopotassium phosphate, calcium nitrate,
and magnesium sulphate in any possible proportions, but do
develop excellently in the 4-salt solution type here employed,
containing the three salts just mentioned and also ammonium
sulphate. It may be of interest to note that the hypothetically
best sets of salt proportions suggested above, T1R1⅛S1⅛ and
T1R1½S1½, are characterized by Ca:Mg ratio values of 1⅛ : 4⅛
(1 : 3.25=0.308) and 1½ : 4 (1 : 2.67=0.375), respectively. If
we adopt the quite undesirable method of considering such ratio
values as derived by considering the two metals as their oxides
and employing the ratio of the weights of the oxides rather than
the atomic or molecular ratio, it may be said that the atomic
ratio Ca:Mg=0.308 is equivalent to the molecular ratio CaO:MgO
=0.308, or the weight ratio CaO:MgO=0.375. The complete
sets of atomic and ionic ratio values for the hypothetically
best set of salt proportions T1R1⅛S1⅛ are as follows (neglecting
the H-ion):

$$K:Ca:Mg:N:P:S=1:1⅛:4⅛:5⅛:1:5\tfrac{3}{4}.$$
$$K:Ca:Mg:NH_4:NO_3:PO_4:SO_4=1:1⅛:4⅛:2\tfrac{3}{4}:2\tfrac{3}{8}:1:5\tfrac{3}{4}.$$

With reference to what sets of molecular salt proportions constitute bad physiological balance for these plants, it has been mentioned that, in general, progressively higher relative partial concentrations of monopotassium phosphate give progressively poorer yields. At the same time it is to be noted that bad physiological balance generally accompanies low relative partial concentrations of magnesium sulphate. Perhaps the worst solution of this 4-salt type may, as here tested, be represented by T3R1S3 or by T4R1S2. These have the molecular salt proportions shown below:

Solution No.	KH₂PO₄.	(NH₄)₂SO₄.	Ca(NO₃)₂.	MgSO₄.
T3R1S3	3	1	3	1
T4R1S2	4	1	2	1

They are characterized by high relative proportions of monopotassium phosphate and calcium nitrate, and by low proportions of ammonium sulphate and magnesium sulphate. But the best solutions for top and root yields are also characterized by low relative proportions of the ammonium salt, as has been seen, so that the distinguishing characters of these very poorly balanced solutions are high proportions of monopotassium phosphate and calcium nitrate and low proportions of magnesium sulphate. From the nature of the results that have been presented and from the nature of the problem itself, it is undesirable to attempt to fix upon any one of the sets of salt proportions as most poorly balanced; to attempt this would lead to discussion of the general problem of toxicity and starvation.

Referring to the studies of earlier students of rice culture and of the salt nutrition of the rice plant, the conclusions just brought forth appear to substantiate the more general ones that have been expressed in the literature; namely, that young rice plants require ammonium and cannot thrive with nitrate as the only source of nitrogen, and that rice needs relatively little potassium and relatively much magnesium, while it cannot generally bear much calcium. An additional point, not emphasized in the literature, is that the best growth of young rice is not to be expected with anything but comparatively low proportions of the ammonium salt, although the present studies suggest that ammonium sulphate is not so injurious in higher proportions as is monopotassium phosphate. Perhaps it may be said to be about as injurious as calcium nitrate.

Lengths of tops and roots.—As has been said, the approximate

average length of tops and of roots was obtained at the end of the culture period, for each culture of series 14 to 20. Discrepancies between the different trials of the same series, as to the relative physiological values of the various sets of salt proportions, are more pronounced in top length than in dry yield, and in root length than in top length, and the general consistency of the whole array of values for top and root length is of a low order. This may be considered as indicating that these length values are not as good criteria as are the dry yields, for bringing out differences in growth in the various cultures as here studied. It should be noted, however, that the method used in obtaining these approximate values involved considerable personal judgment and was not based on precision measurements and mathematical treatment. All things considered, it seems unnecessary to present all these length values here, although some samples for tops will be shown below. In spite of the discrepancies and inconsistencies of this mass of data, it generally appears that sets of salt proportions that appear most satisfactory by the criterion of dry yield also appear very satisfactory by the criterion of top length, and the solutions that appear to be badly balanced according to the one criterion also exhibit very poor growth according to the other.

Table 10 shows the actual and relative top-length values for the three sets of salt proportions chosen as the most promising, and for the two sets chosen as least promising on the basis of dry yields. The relative value is placed in parenthesis after the actual value in each case.

TABLE 10.—*Approximate mean length of tops for selected solution of 4-salt solution type A.*

Solution No.	Series 14, June 19.	Series 15, May 24.	Series 16, June 19.	Series 17, May 1.	Series 18, May 24.	Series 19, June 19.	Series 20, June 19.
	cm.	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*
T1R1S1	30.0(1.00)	40.0(1.00)	35.0(1.00)	38.5(1.00)	36.0(1.00)	33.4(1.00)	31.3(1.00)
T1R1S2	29.5(0.98)	38.3(0.96)	34.4(0.97)	39.0(1.01)	35.0(0.97)	30.0(0.90)	27.7(0.89)
T1R2S1	31.5(1.05)	39.5(0.99)	32.6(0.93)	38.0(0.99)	38.2(1.06)	30.0(0.90)	29.0(0.93)
T3R1S3	26.3(0.88)	30.6(0.77)	27.0(0.77)	26.0(0.68)	29.8(0.83)	23.8(0.71)	17.0(0.54)
T4R1S2	28.5(0.95)	33.5(0.84)	26.6(0.76)	23.0(0.60)	29.3(0.81)	23.0(0.69)	20.3(0.65)

It is clear that the best three sets of salt proportions of Table 10 agree in showing the two medium total concentrations as about alike and markedly better than either the lowest or the highest total concentration here considered, thus supporting the conclusion derived from the data of dry yield. This is not so clear for the two badly balanced sets of salt proportions in this

table, for the values for series 14 are both higher than the corresponding ones for series 19 and one of them is higher than the corresponding one for series 16. It is to be remembered that series 14, 16, 19, and 20 were simultaneously carried out, as also were series 15 and 18. The highest total concentration (series 20) gave top length values much lower than the corresponding ones of any other concentration. As to the comparison between the two medium total concentrations, these two badly balanced sets of salt proportions agree, by both trials, in showing higher values for the low-medium concentration than for the other. Finally, there is no doubt, from the data in Table 10, that the first three solutions belong to the high or well-balanced group, while the last two belong to the low or badly balanced group. On the whole, the indications of these data for top length agree very well with those derived from the dry-yield data for tops and roots.

Green weight and water content of tops.—For the four series carried out in the period beginning June 19, the green weights of tops were determined, and these are shown in Table 11. There were just four series (14, 16, 19, and 20) and each had a different total concentration, so that there are no repetitions to be considered in regard to green weight, but these four series were carried out simultaneously so that they should be comparable as far as non-solution conditions are concerned. In Table 11 the letters H and L are fixed to the values belonging to the high and low groups, respectively, as in the cases of dry yields (Tables 5 and 9).

Considering the comparative physiological values of the four different total concentrations, as shown in Table 11, it is seen that for the lowest total concentration all but one (T4) of the five triangles of the tetrahedral diagram have one or more high green-weight values, and that all but one (T5) have one or more low values also. On the other hand, for the highest total concentration the lowest triangle of the diagram has seven values of the high group and none of the low group, the second triangle has one high value and two low values, and the remaining three triangles have one or more low values each, but no high value. As in the case of the dry yields of tops, the higher the total concentration the more segregated the high values in the lower part of the diagram and the low values in the upper part. As the total concentration is progressively higher the ability of the plants to withstand the higher partial concentration of monopotassium phosphate becomes markedly diminished. For the highest total

TABLE 11.—*Green weight of tops (six plants), actual values, from series with 4-salt solution type A, for culture period June 19 to July 9.*

Solution No.	Total concentration 0.0008 gram-molecule per liter, or 0.04 atmosphere (series 14).	Total concentration 0.0016 gram-molecule per liter, or 0.08 atmosphere (series 16).	Total concentration 0.0038 gram-molecule per liter, or 0.2 atmosphere (series 19).	Total concentration 0.0077 gram-molecule per liter, or 0.4 atmosphere (series 20).
	grams.	grams.	grams.	grams.
T1R1S1	1.24	H1.78	H1.68	H1.39
S2	1.22	H1.69	1.42	H1.12
S3	1.23	1.51	1.36	1.00
S4	1.19	1.45	1.29	0.85
S5	1.00L	1.27	1.07	0.84
R2S1	1.20	H1.56	1.43	H1.12
S2	H1.41	1.31	1.35	H1.24
S3	1.28	1.35	1.33	0.96
S4	1.27	1.25L	1.35	0.91
R3S1	1.24	1.47	H1.46	H1.43
S2	1.23	1.47	H1.53	H1.27
S3	1.28	1.32	H1.57	0.97
R4S1	1.26	1.37	H1.65	H1.26
S2	H1.36	1.28	1.45	1.02
R5S1	1.16L	1.37	1.14	0.86
T2R1S1	1.22	1.45	H1.55	H1.17
S2	1.12L	H1.61	1.06	1.02
S3	1.11L	1.30	1.01L	0.92
S4	1.02L	1.28	0.82L	0.78L
R2S1	1.19	1.48	1.39	0.87
S2	H1.43	H1.80	H1.58	1.02
S3	1.18L	1.02L	1.13	0.79L
R3S1	H1.40	1.32	1.04L	H1.08
S2	1.35	1.42	1.18	0.96
R4S1	1.28	1.42	1.31	0.82
T3R1S1	1.27	H1.52	1.02L	0.99
S2	H1.38	1.30	1.10	0.93
S3	1.15L	1.21L	0.94L	0.45L
R2S1	H1.42	H1.55	1.13	1.06
S2	1.29	1.09L	1.06	0.72L
R3S1	H1.54	1.44	1.14	0.76L
T4R1S1	1.16L	1.14L	1.26	0.82
S2	1.11L	1.05L	0.75L	0.76L
R2S1	1.35	1.23L	1.10	0.57L
T5R1S1	H1.40	1.21L	0.84L	0.75L

concentration, no high value occurs for any set of salt proportions in which monopotassium phosphate makes up more than two-eighths of the total molecular concentration. For the lowest total concentration this salt may make up five-eighths of the total and a high green-weight value may be produced.

Furthermore, low values shown in the lower two or three triangles of the diagram correspond to relatively low partial concentration of magnesium sulphate, and to high ones of cal-

cium nitrate, and the high values in these triangles correspond to high partial concentrations of magnesium sulphate and low ones of the calcium salt.

Considering each set of salt proportions singly, it is seen from Table 11 that the highest green weight most generally occurs with the low-medium total concentration (series 16) ; this is true for 20 out of the 35 sets of salt proportions tested.   Of the remaining 15 sets, 7 show the highest green weight for the high-medium total concentration (series 19), and in all other cases (8) the highest value occurs for the lowest total concentration (series 14) ; in no case does the highest total concentration (series 20) give the highest green-weight value.   This supports the conclusion reached from the study of the dry yields of tops and roots, that both of the medium concentrations are to be considered relatively good for these plants, but that the low-medium total concentration is probably to be regarded as more nearly optimal than the high-medium.   The last point is more strongly emphasized here than in the case of dry yields.

Green weight of tops has frequently been employed as a criterion for comparing the physiological efficiencies of different environmental complexes, although it does not appear to have been used by earlier workers with solution cultures arranged for a thorough study of salt proportions. Since green weight consists, in any case, of the corresponding dry weight plus the corresponding water content, it is quite possible that the green-weight criterion (or the water content per weight unit of dry yield, or per weight unit of green weight itself) may bring out other physiological relations than those shown by the dry-yield criterion.   For example, with a given total concentration, one set of salt proportions may give a higher dry-yield value than is given by another set, or the two sets may give equal values, and at the same time the first set may give a percentage of water content either less, equal to, or greater than that given by the other set.   The salt proportions may influence not only the dry-yield production but also (possibly in an entirely different manner) the power of the plant to retain water.   Two plants may have the same dry weight but may be markedly different physiologically (and in regard to commercial value), according to the amount of water retained in their tissue; one might be much more succulent than the other, etc.   Such possibilities are suggested in the literature.

On account of these considerations it will be valuable to make a comparison between the indications of the dry-yield and of

the green-weight criteria for these four simultaneous series with young rice plants; for these cultures the dry yields of tops are also available, as has been shown. For the sake of this comparison Table 12 has been prepared. On account of the numerous discrepancies among the indications from repeated series it seems best not to consider any dry yield data here excepting those of the four simultaneous series in question, where the proposed comparisons may be made directly and without any complications introduced by differences in climatic and other non-

TABLE 12.—*Comparison between dry yield and green weight of tops, as to the indications from the four simultaneous series (14, 16, 19, and 20), beginning June 19.*

Solution No.	Lowest total concentration (series 14).		Low-medium total concentration (series 16).		High-medium total concentration (series 19).		Highest total concentration (series 20).	
	Dry.	Green.	Dry.	Green.	Dry.	Green.	Dry.	Green.
T1R1S1	M	M	H	H	H	H	H	H
S2	M	M	H	H	M	M	M X	H
S3	M	M	H X	M	M	M	M	M
S4	L X	M	M	M	M	M	M	M
S5	L	L	M	M	L X	M	M	M
R2S1	M	M	H	H	H X	M	H	H
S2	H	H	M	M	M	M	H	H
S3	H X	M	M	M	M	M	M	M
S4	H X	M	L	L	M	M	M	M
R3S1	H X	M	H X	M	M X	H	H	H
S2	M	M	H X	M	H	H	H	H
S3	M	M	M	M	H	H	M	M
R4S1	M	M	M	M	H	H	H	H
S2	H	H	M	M	H X	M	M	M
R5S1	M X	L	M	M	M	M	M	M
T2R1S1	M	M	M	M	H	H	H	H
S2	L	L	M X	H	M	M	M	M
S3	L	L	L X	M	M X	L	M	M
S4	L	L	L X	M	L	L	L	L
R2S1	M	M	H X	M	M	M	M	M
S2	H	H	H	H	H	H	M	M
S3	L	L	L	L	L X	M	L	L
R3S1	H	H	M	M	L	L	M X	H
S2	H X	M	M	M	M	M	M	M
R4S1	M	M	M	M	M	M	L X	M
T3R1S1	M	M	M X	H	L	L	M	M
S2	M X	H	M	M	L X	M	M	M
S3	L	L	L	L	L	L	L	L
R2S1	H	H	H	H	L X	M	M	M
S2	M	M	L	L	L X	M	L	L
R3S1	H	H	M	M	L X	M	L	L
T4R1S1	M X	L	L	L	M	M	L X	M
S2	L	L	L	L	L	L	L	L
R2S1	H X	M	L	L	M	M	L	L
T5R1S1	H	H	L	L	L	L	L	L

solution conditions. For the same reason, the detailed values need not be considered, attention being confined to the group designations only, for both dry yield and green weight. Table 12 shows the group designations (high, medium, or low) for dry yield and green weight of tops, for each set of salt proportions and for each of the four different total concentrations. In this table each series has a double column, the first for the dry yield and the second for the green weights. Where the group designations are different in the two cases the letter X is placed in the space between the two values; this brings out the frequency of discrepancies and shows for what sets of salt proportions and total concentrations they occur.

Inspection of Table 12 leads to the impression that dry yield and green weight are generally in agreement as far as placing the various culture solutions in the low, medium, or high group is concerned. Out of one hundred forty comparisons between the indications given by these two criteria only thirty-one, or 22 per cent of the total number, fail to show agreement. This means that the two criteria agree in 78 per cent of the cases; and, since these cases of agreement represent the whole range of environmental complexes here studied, it may be concluded that the two criteria are generally both influenced in about the same way, by total concentration, salt proportions, and non-solution conditions. It should be emphasized that this conclusion is to be regarded as holding only for the plants and environments dealt with in these experiments; such a generalization is not warranted for the whole plant kingdom or for other solution types, etc. It may or may not hold for these other conditional complexes, for other plants (or for lowland rice plants in later developmental stages), etc.

With this warning as to the danger of attempting to generalize beyond the limits of the field actually investigated (a danger that seems not always to be appreciated fully in biological writing), attention may be turned more specifically to the cases that show disagreement in the indications of the two criteria here considered. In the first place, it may be inquired whether these discrepancies are any more or any less frequent with one total concentration than with another. Table 12 shows nine disagreements for the lowest total concentration, eight for the low-medium, ten for the high-medium and only four for the highest total concentration; it therefore appears that, with higher total concentrations than are well suited to the development of this plant with this type of solution, the agreement between dry yield

and green weight of tops may be expected to be better than
occurs for what may be termed the optimal range of total con-
centration.   The three less concentrated series nearly agree
with one another in this regard, but the series with highest
concentration shows less than half the number of discrepancies
that any one of the other three shows.   This fact may or may
not be important; of course it is to be understood that, if the
total concentration were made high enough to injure the plants
seriously, each of the various dry yields must approach the.
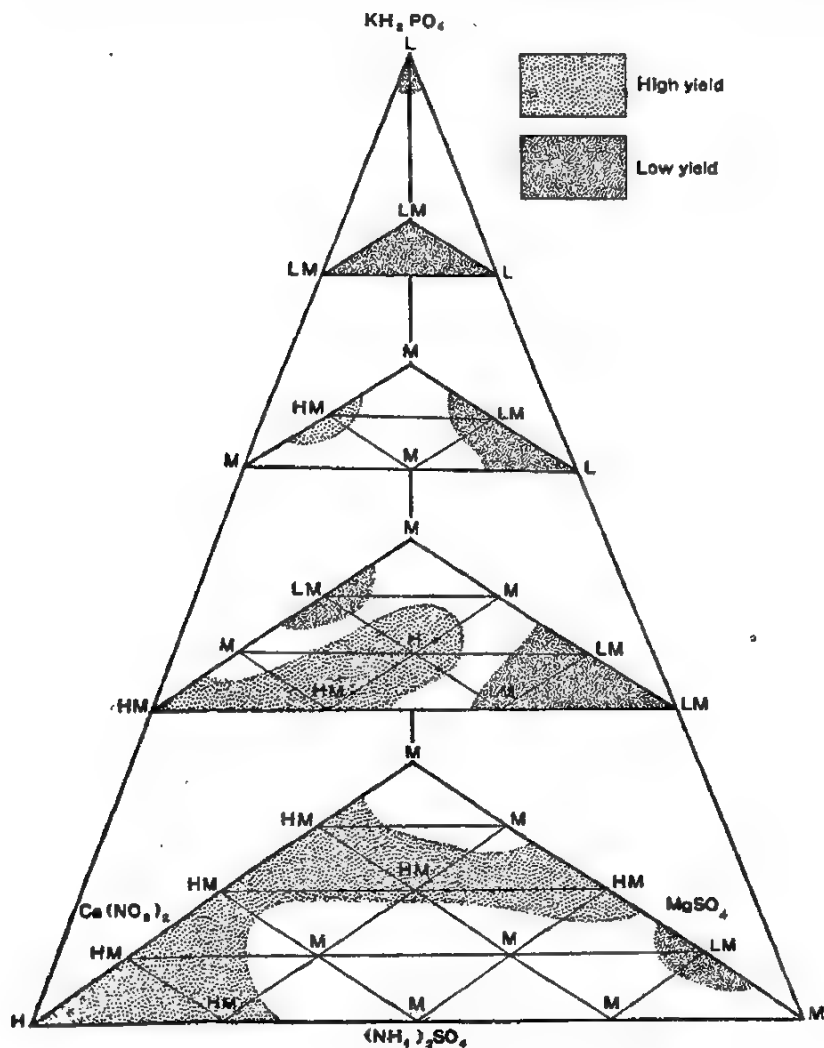

Fig. 8.   Distribution of low, medium and high green-weight values for series 16 and 19
combined.

corresponding green weight, as both approached the zero value where all growth was inhibited.

Turning next to the relation between the discrepancies shown in Table 12 and the various sets of salt proportions, it may be remarked that there are just three cases in which a discrepancy is recorded for two or more total concentrations of the same set of salt proportions. One of these cases refers to solution T1R3S1, for which disagreement between the two criteria is shown for the lowest three total concentrations, but not for the highest. The second case refers to solution T2R1S3, for which disagreement is recorded for the two medium total concentrations. The third case refers to solution T4R1S1, for which there is disagreement for the lowest and for the highest total concentration. Altogether, it appears that there is no evident relation between salt proportions, which supports the generalization stated on page 508, to the effect that these two criteria generally agree in their indications, and that (for the present study) one is to be regarded as about equivalent to the other.

Considering only the two medium total concentrations, the distribution of the low, medium, and high values of the green weight of tops, with reference to salt proportions, may be brought out diagrammatically as in the case of the dry yields. This is done by fig. 8, which is constructed in a manner similar to that followed for figs. 4 to 7. The letter designations shown for green weight and for the two medium total concentrations (series 16 and 19) in Table 12 have been placed on the tetrahedral diagram (HL being replaced by M, as for the dry-yield diagrams) and the high and low areas have been demarked and distinguished by shading. For this particular diagram the HM-points are included in the high regions, and the LM-points are included in the low regions.

From this diagram it appears at once that this sort of summary of the green-weight data leads to the same general conclusions as were reached from the study of the dry-yield data. It appears that the most promising set of salt proportions on this basis is T1R1S1, and the least promising ones are T2R1S4, T3R1S3, T4R1S2, and T5R1S1 (the top apex). It seems safe, however, to allow the general conclusions derived from dry yields to stand as they are, and merely to remark that the points there emphasized are supported and substantiated by the indications derived from green weight of tops.

It is clear from what precedes that the thirty-five sets of salt

proportions and the four total concentrations here dealt with did not differ significantly in their influence upon the ability of the plant tops to retain water. Calculating the water content as percentage of the corresponding green-weight value the result shows that the total range of these values is only from 79 to 87.5 per cent, and most of the values lie between 83 and 86. It may be said that these tops were sensibly equally succulent for all cultures, irrespective of the total concentration or of the salt proportions. It is also clear that these tops were uniformly re-

TABLE 13.—*Water absorption (cubic centimeters per six plants) during the culture period, for series 14, 16, 19, and 20, beginning June 19.*

Solution No.	Total concentration 0.0008 gram-molecule per liter, or 0.04 atmosphere (series 14).	Total concentration 0.0016 gram-molecule per liter, or 0.08 atmosphere (series 16).	Total concentration 0.0038 gram-molecule per liter, or 0.2 atmosphere (series 19).	Total concentration 0.0077 gram-molecule per liter, or 0.4 atmosphere (series 20).
	cc.	cc.	cc.	cc.
T1R1S1	188	H 229	H 197	H 168
S2	185	H 196	168	H 154
S3	185	188	165	137
S4	174	187	157	127
S5	155 L	163 L	142 L	124
R2S1	190	H 205	H 177	143
S2	H 206	188	164	H 163
S3	H 194	183	170	134
S4	H 198	162 L	160	129
R3S1	192	190	173	H 176
S2	H 204	189	H 184	H 155
S3	H 206	170	H 191	134
R4S1	192	187	H 204	H 163
S2	H 206	178	H 180	H 150
R5S1	169 L	183	154	136
T2R1S1	181	189	H 184	142
S2	145 L	190	155	139
S3	153 L	166	170	131
S4	146 L	161 L	120 L	123
R2S1	167 L	H 191	173	128
S2	H 199	H 217	H 194	142
S3	160 L	143 L	142 L	123
R3S1	H 201	174	153	H 145
S2	186	183	158	138
R4S1	175	176	169	113 L
T3R1S1	176	H 193	138 L	134
S2	181	166	146	136
S3	160 L	162 L	128 L	91 L
R2S1	H 194	H 194	152 ;	135
S2	176	153 L	144 L	120 L
R3S1	H 210	190	150	119 L
T4R1S1	173	150 L	161	115 L
S2	153 L	145 L	108 L	109 L
R2S1	191	162 L	154	105 L
T5R1S1	H 199	167	126 L	109 L

latively very dry, as compared with active plant tissues in general, and that the drying of leaf tips that occurred in many of the poorer cultures was without marked effect upon the percentage of water content.

In considering the green weight as a criterion for comparing the physiological efficiency of different cultures, etc., it should be remembered that there is probably a more or less pronounced daily fluctuation in the water content of leaves and small stems, as has been emphasized by Livingston and Brown,[30] by Renner,[31] by Edith B. Shreve,[32] by Yuncher,[33] and by others.

Water absorption.—The four simultaneous series carried out in the period beginning June 19 (series 14, 16, 19, and 20) also furnished comparative data on water absorption, which are presented in Table 13. These values are the amounts of water, in cubic centimeters, absorbed during the entire culture period.

Considering the very small amount of water retained by the plants (see the green weights and dry yields of tops), the absorption values clearly represent the amounts of water transpired, which, as Livingston[34] has shown, may be generally considered as an approximate index of the leaf area, at least for young wheat plants. In studies like the present one the use of the total amount of water transpired during the growth period, as a criterion for comparing the plants of different cultures, seems to have been inaugurated by Whitney and Cameron,[35] and it has been continued by Livingston, Britton, and Reid,[36] and by many other later workers. It appears that Shive (1915) was the first, at least among those who have been engaged in the recent systematic study of salt relations by the method of solution cultures, to employ water absorption instead of transpirational water loss. Since this gives another quantitative criterion by which plants

[30] Livingston, B. E., and Brown, W. H., Relation of the daily march of transpiration to variation in water content of leaves, Bot. Gaz. 53 (1912) 309–330.

[31] Renner, O., Beiträge zur Physik der Transpiration, Flora 100 (1910) 451–547.

[32] Shreve, Edith B., The daily march of transpiration in a desert perennial, Pub. Carnegie Inst. Washington (1914) No. 149.

[33] Yuncher, T. G., A study of the relation of soil moisture to transpiration and photosynthesis in the corn plant, Plant World 19 (1916) 151–161.

[34] Livingston, B. E., Relation of transpiration to growth in wheat, Bot. Gaz. 40 (1905) 178–195.

[35] Whitney, M., and Cameron, F. K., Investigation in soil fertility, Bull. U. S. Dept. Agr., Bur. Soils 23 (1904).

[36] Livingston, B. E., Britton, J. C., and Reid, F. R., Studies on the properties of an unproductive soil, Bull. U. S. Dept. Agr., Bur. Soils 28 (1905) 39.

may be compared, and especially since the amount of water absorption is much more easily determined for solution cultures than is any other quantitative plant value, it seemed desirable to make these water-absorption determinations in the present study.

The data in Table 13 show that the highest values are not generally found for the two medium total concentrations as was the case for dry yield and green weight. It is commonly understood that, except in special cases, the lower the total concentration the higher the rates of water absorption and transpiration, providing that the plants to be compared are all fairly healthy, and that all have been exposed to the same set of non-solution conditions. In spite of this consideration, however, the very highest water-absorption values for the one hundred forty simultaneous cultures here dealt with are for the low-medium total concentration (solutions T1R1S1 and T2R2S2). The highest total concentration here considered generally gives values lower than the corresponding ones of the other three total concentrations. Without trying to determine which one of the solutions may be expected to show the highest absorption rates, we may turn to the two medium total concentrations and make a comparison between their group designations (H and L) and those obtained from these two total concentrations in terms of dry yield and green weight of tops.

Such a comparison may be instituted by means of Table 14, which is a reproduction of Table 12 with the water-absorption designations added as a third column for each series. The method followed is the same as was used for Table 12, and the notation is the same throughout.

Examination of Table 14 shows that the group designations for water absorption generally agree with those for green weight, and in the majority of cases agreement is perfect for all three criteria. In each of these four series there are from five to eight discrepancies between the evidence from green weight and that from water absorption, but there seems to be no relation between the number of discrepancies and the total concentration, unless such evidence may be suggested by the fact that series 16 (with the low-medium concentration) shows only five disagreements of this kind, while series 14 and 20 show seven each, and series 19 shows eight. It may be concluded immediately that water absorption is apparently just as satisfactory in discriminating between the different cultures of any series as is either dry yield or green weight. All three criteria appear to be about equally valuable.

TABLE 14.—*Comparison between dry and green weight of tops and water absorption, as to the indications from the four simultaneous series (14, 16, 19, and 20), beginning June 19.*

Solution No.	Lowest total concentration (series 14).			Low-medium total concentration (series 16).			High-medium total concentration (series 19).			Highest total concentration (series 20).		
	Dry yield.	Green wt.	Abs.	Dry yield.	Green wt.	Abs.	Dry yield.	Green wt.	Abs.	Dry yield.	Green wt.	Abs.
T1R1S1	M	M	M	H	H	H	H	H	H	H	H	H
S2	M	M	M	H	H	H	M	M	M	M X	H	H
S3	M	M	M	H X	M	M	M	M	M	M	M	M
S4	L X	M	M	M	M	M	M	M	M	M	M	M
S5	L	L	L	M	M X	L	L X	M	X L	M	M	M
R2S1	M	M	M	H	H	H	H X	M X	H	H	H X	M
S2	H	H	H	M	M	M	M	M	M	H	H	H
S3	H X	M X	H	M	M	M	M	M	M	M	M	M
S4	H X	M X	H	L	L	L	M	M	M	M	M	M
R3S1	H X	M	M	H X	M	M	M X	H X	M	H	H	H
S2	M	M X	H	H X	M	M	H	H	H	H	H	H
S3	M	M X	H	M	M	M	H	H	H	M	M	M
R4S1	M	M	M	M	M	M	H	H	H	H	H	H
S2	H	H	H	M	M	M	H X	M X	H	M	M X	H
R5S1	M X	L	L	M	M	M	M	M	M	M	M	M
T2R1S1	M	M	M	M	M	M	H	H	H	H	H X	M
S2	L	L	L	M X	H X	M	M	M	M	M	M	M
S3	L	L	L	L X	M	M	M X	L X	M	M	M	M
S4	L	L	L	L X	M X	L	L	L	L	L	L X	M
R2S1	M	M X	L	H X	M X	H	M	M	M	M	M	M
S2	H	H	H	H	H	H	H	H	H	M	M	M
S3	L	L	L	L	L	L	L X	M X	L	L	L X	M
R3S1	H	H	H	M	M	M	L	L X	M	M X	H	H
S2	H X	M	M	M	M	M	M	M	M	M	M	M
R4S1	M	M	M	M	M	M	M	M	M	L X	M X	L
T3R1S1	M	M	M	M X	H	H	L	L	L	M	M	M
S2	M X	H X	M	M	M	M	L X	M	M	M	M	M
S3	L .	L	L	L	L	L	L	L	L	L	L	L
R2S1	H	H	H	H	H	H	L X	M	M	M	M	M
S2	M	M	M	L	L	L	L X	M X	L	L	L	L
R3S1	H	H	H	M	M	M	L X	M	M	L	L	L
T4R1S1	M X	L X	M	L	L	L	M	M	M	L X	M X	L
S2	L	L	L	L	L	L	L	L	L	L	L	L
R2S1	H X	M	M	L	L	L	M	M	M	L	L	L
T5R1S1	H	H	H	L	L X	M	L	L	L	L	L	L

Looking further into this matter of disagreements between the indications of green weight and those of water absorption, it is seen that where this kind of discrepancy occurs along with a disagreement between the indications of dry yield and those of green weight, the three designations (L, M, and H) never occur together; there are always two like designations and one different one. A similar statement holds for the entire series of disagreements shown in Table 14; wherever a discrepancy

occurs it is between two contiguous groups, H and M, or M and
L.   These considerations constitute still further evidence in favor
of the conclusion that all these plant criteria are about the same
in their indications as to the relative physiological values of the
various sets of salt proportions.

As in previous cases, it is instructive to place the water-absorp-
tion designations for the two medium total concentrations on
the tetrahedral diagram and then indicate the regions of high
and low values.   Such a diagram is shown in fig. 9, which
is markedly like the diagrams, figs. 4 to 8.   The experi-
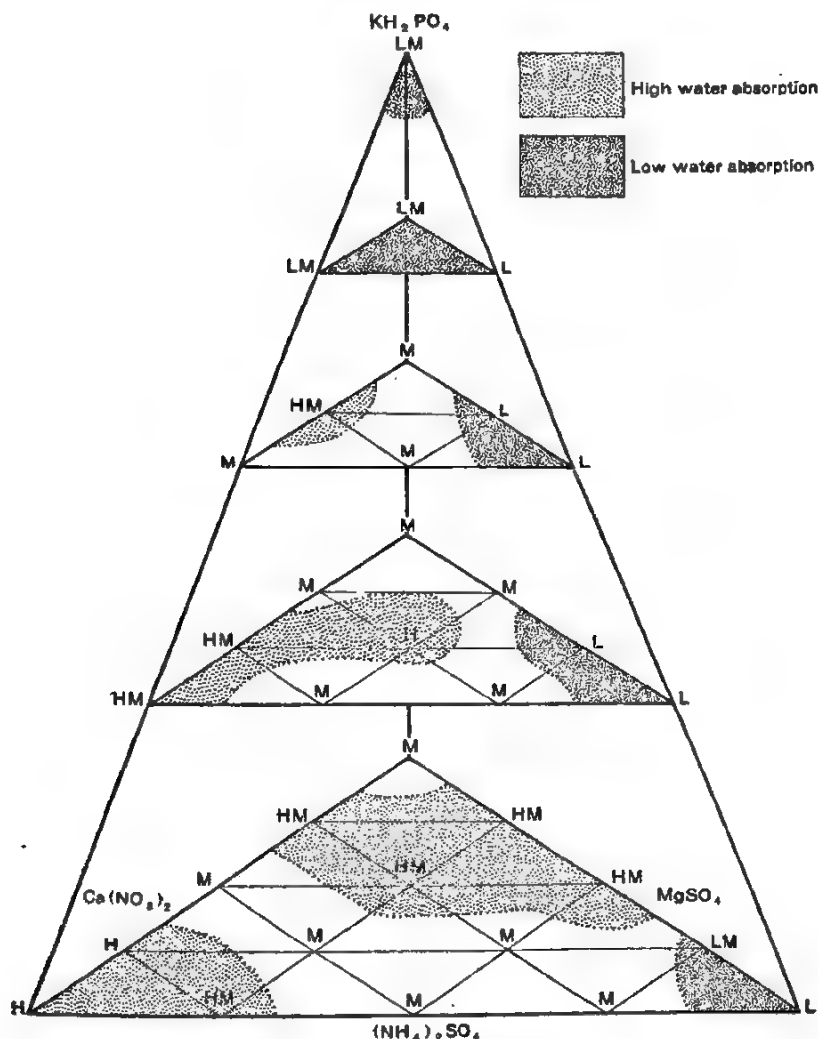
Fig. 9. Distribution of low, medium and high water-absorption values for series 16 and 19.

mental data are so limited that detailed discussion of the differences is not warranted. It is clear, from the yield data, that the three sets of salt proportions selected as most generally promising are shown as most promising by the water-absorption data, as well as by the data for green weight. Also the two sets of salt proportions selected to represent badly balanced cultures are shown as belonging to the low group in fig. 9.

FOUR-SALT TYPE B (MONOPOTASSIUM PHOSPHATE, MONOCALCIUM PHOSPHATE, MAGNESIUM SULPHATE, AMMONIUM SULPHATE)

As has been mentioned, the tests with the four-salt solution type B were carried out to determine whether the nitrate ion in the solutions of type A might be unnecessary, or even harmful. The lowest section of Table 3 shows the six experimental series that were carried out with this type of solution, three total concentrations (0.0008, 0.0016, and 0.0038 gram-molecule per liter, or 0.04, 0.08, and 0.2 atmosphere) being simultaneously employed for the period beginning August 3 (series 23, 25, and 27), and again for that beginning September 9 (series 24, 26, and 28).

The better cultures of each series showed very satisfactory growth, excepting that the plants were always markedly affected in the latter part of the three-week period by a characteristic drying of the leaves backward from the tips. This was so pronounced and so characteristic of these type B solutions that it must be regarded as a serious form of physiological injury. The dry yields of tops and of roots gave values not markedly lower than the corresponding ones obtained with solution type A, but the presence of the injury just mentioned made it impossible to regard even the best sets of salt proportions of type B as in any way approaching physiological equality with the best ones of type A. For this reason the data of series 23 to 28 will not be presented in the present paper. It may be noted further, however, that the highest total concentration here used (corresponding to the high-medium of solution type A) proved to be too high for the best growth, and that the lowest one here used seemed to be somewhat too low. The most promising solutions of this type had what was termed in the preceding discussions the low-medium total concentration (0.0016 gram-molecule per liter, or 0.08 atmosphere). It will be recalled that this total concentration seemed to be somewhat more promising than the others for type A. For type B, however, emphasis appears to be placed on the lowest and the low-medium total concentration rather than on the low-medium and the high-medium.

On account of the pronounced leaf injury present even in the

best cultures of solution type B, it is concluded that this type is not at all well suited to the growth of these young rice plants, at least under the non-solution conditions here dealt with. A direct and simultaneous comparison between some of the best sets of salt proportions for type B with some of the best ones for type A will be considered in the following section of this paper.

It should be remembered that 4-salt solution type B represents only one of many possible ways by which the ions potassium, calcium, magnesium, ammonium, phosphate, and sulphate might be brought together in solutions, without any nitrate, and the failure of any of these sets of salt proportions to give satisfactory growth in the plants here used is not to be regarded as definite proof that young rice plants actually require the nitrate ion. All that may be said is that these plantlets grew excellently well with certain sets of salt proportions of the 4-salt solution type with both ammonium and nitrate, while no set of proportions tried with ammonium but without nitrate gave passable development, on account of the generally present leaf injury.

FINAL COMPARISON BETWEEN THE THREE DIFFERENT SOLUTION TYPES

After the experiments whose results have thus far been considered had been completed and after the data given by them had been studied to some extent, but before the method of basing conclusions on agreement in group designations had been hit upon, the apparently best three sets of salt proportions were selected from each of the three solution types, for each of the lowest two total concentrations, and these were employed in a set for simultaneous test. In this lot there were thus six solutions of 4-salt type A, six of 4-salt type B, and three of 3-salt type I (increments of one-seventh). To these were added two different total concentrations of Shive's best solution for young wheat plants (3-salt type I, osmotic proportions, increments of one-tenth). Four like cultures, of 6 plants each, were employed in each case. The methods and treatment were the same as for the preceding larger series, and the culture period was from March 13 to April 3, 1919. The solution characteristics and the dry-yield data for tops, roots, and entire plants (each representing 6 plants but each derived as an average from four like cultures of 6 plants each) are presented in Table 15. The numerical data are all expressed in terms of the corresponding yield value for solution AT1R2S1 (0.0016 gram-molecule per liter, or 0.08 atmosphere), taken as unity, the actual value for this solution being given in parentheses beneath the value 1.00.

TABLE 15.—*Relative yields of tops, roots, and entire plants for selected solutions of 4-salt type A, 4-salt type B, and 3-salt type I, final comparative series.*

[Data are for six plants, being averages from four cultures of six plants each.]

Solution No.	Total concentration.		Dry yield.		
	Gram-molecule per liter.	Atmosphere.	Tops.	Roots.	Entire plants.
AT1R2S1	0.0016	0.08	*1.00 (0.169 g.)	*1.00 (0.079 g.)	*1.00 (0.996 g.)
AT1R2S2	0.0008	0.04	0.94	1.05	0.96
AT2R3S1	0.0008	0.04	0.93	0.94	0.98
AT3R3S1	0.0008	0.04	0.83	1.00	0.88
AT2R1S1	0.0016	0.08	0.81	1.02	0.88
AT2R2S2	0.0016	0.08	0.72	0.94	0.79
BT2R1S1	0.0016	0.08	0.97	1.02	0.99
BT1R2S1	0.0008	0.04	0.87	1.04	0.98
BT2R1S2	0.0016	0.08	0.85	1.03	0.91
BT1R2S2	0.0008	0.04	0.84	1.02	0.90
BT3R1S1	0.0016	0.08	0.81	1.00	0.87
BT3R2S1	0.0008	0.04	0.84	1.04	0.87
1R2S1[b]	0.0022	0.10	0.44	0.89	0.69
1R3S1[b]	0.0022	0.10	0.40	0.90	0.57
1R4S1[b]	0.0022	0.10	0.40	0.87	0.55
1R5S2[c]	0.0022	0.10	0.44	0.94	0.69
1R6S2[c]	0.0332	1.75	0.47	0.92	0.62

[a] All values are expressed in terms of the corresponding one for solution AT1R2S1 and the actual value for this solution is given in parentheses beneath the relative value 1.00.
[b] Increment one-seventh.
[c] Increment of one-tenth osmotic proportions.

Although the data in Table 15 are derived from twenty-four plants grown simultaneously in four cultures of six plants each, as has been stated, and although it may be assumed that the aërial complex of conditions was practically the same for all, yet it seems necessary to disregard all minor differences brought out in the table. With this consideration in view, we may allow a plus or minus variation of 0.05 as negligible, so that 0.95 in the table becomes equivalent to all values from 0.95 to 1.05, inclusive. In other words, the values from 0.95 to 1.05 may be considered as practically alike, all lying within the best group. On the basis of this agreement it is seen that just two solutions agree in belonging to the best group for all three criteria (yields of tops, roots, and entire plants), and that these two solutions are AT1R2S1 and BT2R1S1. It must be remarked, however, that the second of these solutions, and all of the B type in this series, produced the characteristic form of leaf injury noted above, so that this solution is not to be regarded as nearly so

well balanced as is AT1R2S1. The last-named solution is un-doubtedly the most promising of the present series, and it is the only one of the three previously selected as representing good physiological balance, that was included in the present series. The data of Table 15 therefore support the conclusion reached from the more thorough study of type A; namely, that T1R1S1, T1R2S1, and T2R1S1 are to be regarded as about equal and as very well balanced for these plants. This conclusion is especially strengthened by the fact that the solutions tested in the present series were selected because they showed high values in earlier tests, but before the analysis by agreements and disagreements had been completed. It is unfortunate that solutions AT1R1S1 and AT1R1S2 were not included in the final series.

It is of interest to emphasize that solution type B is shown to be capable of giving yield values of the best group, in spite of the fact that these solutions always produced marked leaf injury.

With regard to the 3-salt solutions of the final series, Table 15 shows that the representative of this type gave entire plant yields of 0.62 or below, and top yields of 0.47 or below, while their root yields approach very nearly to being included in the best group, their values being from 0.87 to 0.94. It may be suggested that the best sets of salt proportions of the 3-salt type I series of solutions, with the two low total concentrations as well as with the single higher one found to be nearly optimal for wheat plantlets (Shive), are very well balanced for the production of dry root yields, although they are very badly balanced according to the criteria of top yields or entire plants. This suggestion may possibly be of importance at some later time when the relations between the physiology of roots and that of tops is better understood and attracts more attention than is now the case.

It is obvious enough from Table 15 that none of these best 3-salt solutions is at all well suited for young rice plants; they all belong in the poor group of this series, on the basis of yields both of tops and of whole plants. This result of the final series supports that reached on the basis of appearance of the plants, as stated in an earlier section of this paper.

The last two solutions shown in Table 15 deserve special attention. These have the salt proportions of Shive's best so-lution for young wheat plants (IR5S2); they are based on the scheme of osmotic (instead of molecular) proportions and on the triangular diagram with increments of one-tenth (instead of

one-seventh, as in the case of the other 3-salt solutions here considered). It is a noteworthy fact that, although these rice plantlets have shown themselves very sensitive to total concentration for the well-balanced solutions (best ones of types A and B), yet the yield values shown in Table 15 are practically the same for both total concentrations here included. This set of salt proportions is badly balanced for young rice plants but it gives equally good yields whether the total concentration has an osmotic value of 0.1 or of 1.75 atmospheres. This equality was not shown, however, by the appearance of the plants; those with more concentrated solution were much more stunted than those with the weaker one (see Plate 1).

As to general appearance, all the plants with solution type A looked about alike; the differences brought out by the dry yields were not apparent. Also, the plants with solution type B were like those with type A in appearance, excepting for the leaf injury characteristic of the former group. On the other hand, the plants with 3-salt solution type I were all obviously much stunted and the leaves were yellowish rather than of the deep green color found in the case of types A and B in this series. Comparison of the two Shive solutions (0.1 and 1.75 atmospheres) shows that the one with the higher concentration exhibited much smaller and more stunted plants than did the other, in spite of the similar dry-yield values from these two solutions, as has been remarked. An idea of the general appearance of these plants may be gained from the photographs given in Plate 1, which requires no further description than that given by its legend.

To summarize, this final comparative series still further emphasizes and supports the conclusions reached before; namely, that 3-salt solution type I (with nitrate but without ammonium) offers no promise, with any possible set of salt proportions, for good growth of lowland rice plants; that 4-salt solution type A (with both ammonium and nitrate) gives excellent growth of these plants with salt proportions about like those of solution T1R1S1, and with total concentrations between 0.0008 and 0.0016 gram-molecule per liter (0.04 and 0.08 atmosphere); and that 4-salt solution type B (with ammonium but without nitrate) may give excellent dry yields with properly selected sets of salt proportions (as T2R1S1), but is nevertheless badly balanced for the successful growth of rice plants on account of leaf injury.

SUMMARY

The studies here reported deal with the mineral nutrition of lowland rice plants in solution cultures, for the phase of their development represented by the three-week period following germination. They involve experimental data on the growth of the plants in three different types of solutions: 3-salt solution type I comprising, besides a trace of ferric phosphate, the three salts monopotassium phosphate, calcium nitrate, and magnesium sulphate; 4-salt solution type A comprising, besides a trace of ferric phosphate, the three salts just mentioned together with ammonium sulphate; and 4-salt solution type B comprising, besides a trace of ferric phosphate, the four salts monopotassium phosphate, monocalcium phosphate, magnesium sulphate, and ammonium sulphate. Each type was studied with reference to a large number of different sets of salt proportions and several different total salt concentrations. The experiments were carried out in the spring and summer in a greenhouse in Baltimore, and the results are to be considered as applicable to the climatic conditions prevailing there.

For each solution type the various sets of salt proportions were arranged on the basis of molecular proportions, instead of on osmotic proportions, as was done in several previous studies dealing with salt proportions and physiological balance in nutrient media. With this improvement in the method of planning and preparing the numerous solutions to be tested it is possible to make up a single, somewhat highly concentrated stock solution for any given set of molecular salt proportions and, by simple dilution of portions of this stock solution, to obtain solutions with the same set of salt proportions but with lower concentrations.

The following are the main generalizations derived from the experimental data:

1. No set of salt proportions of 3-salt type I gave even fair growth.

2. Excellent growth was obtained with proper sets of salt proportions of 4-salt solution type A. This suggests that these plants require the ammonium ion, thus apparently differing from many other plant forms.

3. It appears highly improbable that young rice plants could thrive with any 3-salt type of solution; there is no doubt that rice requires the kations potassium, calcium, and magnesium (as well as a little ferrum) like other plants, and the ammonium-ion cannot be introduced into a 3-salt solution without its being the

kation of one of the three salts used, which means that its introduction can be accomplished (in a 3-salt solution) only by omitting either potassium, calcium, or magnesium.

4. With 3-salt solution type I the nearest approach toward good growth was obtained. With solutions in which not more than one-eighth of the molecular total is due to calcium nitrate, the proportions of the other two salts seem to have been without influence in determining which sets of salt proportions were least badly balanced.

5. The best sets of salt proportions of 4-salt solution type A gave the most satisfactory growth that was obtained.

6. The best solutions of type B gave about as good growth as did the best ones of type A, by the criteria of size, yield, and water-absorption; but even these best solutions of type B always produced a marked and characteristic leaf injury, so that no solution of this type is to be regarded as at all suited to the growth of these plants. This suggests that these young rice plants require (at least within the range of these experiments) not only the ammonium ion but also the nitrate ion.

7. The best solution for these plants is one that has a total concentration of 0.0016 or 0.0038 gram-molecule per liter (of all salts taken together), or an osmotic value of about 0.08 or about 0.2 atmosphere. It may be said that the most promising total concentration for these plants lies between these limits, probably nearer the lower one. The best total concentration for young rice plants is thus very much lower than that for any other form of plant hitherto studied by these general methods. (Wheat thrives best with a total concentration represented by an osmotic value of between 1.5 and 2.5 atmospheres.)

8. For the range of total concentration just mentioned (0.08 to 0.2 atmosphere) the best solutions (4-salt type A) are characterized by having very high relative molecular partial concentrations of magnesium sulphate. They generally have comparatively low relative molecular partial concentrations of monopotassium phosphate and calcium nitrate. The most promising solution for these plants may be stated as having about 0.002 gram-molecule per liter (of all salts), the salts being present in about the following molecular proportions:

$$KH_2PO_4 : (NH_4)_2SO_4 : Ca(NO_3)_2 : MgSO_4 = 1 : 1\frac{1}{2} : 1\frac{1}{2} : 4.$$

It is safe to say that one very excellent solution would have the potassium, ammonium, and calcium salts in about the same proportions, while the molecular partial concentration of the

magnesium salt should be four or five times as great as that of any one of the others. The tolerance of these plants for magnesium sulphate is especially remarkable.

9. The results of these experiments led to the conclusion that good growth of tops was generally accompanied by good growth of roots, a feature with regard to which these plants seem to differ from wheat.

10. Dry yield of tops, dry yield of roots, green weight of tops, and the amount of water absorbed during the three-week period, all appear to furnish valuable criteria for comparing growth in these different solutions, and all four criteria are in good general agreement.

ILLUSTRATIONS

PLATE 1

Representative cultures of the final comparative series, at the end of the culture period.

FIG. 1. Four-salt type A, T1R2S2 (0.04 atmosphere).
2. Four-salt type A, T2R1S1 (0.08 atmosphere).
3. Four-salt type A, T2R2S2 (0.08 atmosphere).
4. Four-salt type B, T2R1S2 (0.08 atmosphere).
5. Four-salt type B, T1R2S1 (0.04 atmosphere).
6. Three-salt type I (molecular proportions, increments of one-seventh R2S1 (0.00217 gram-molecule per liter, or 0.1 atmosphere).
7. Three-salt type I (osmotic proportions, increments of one-tenth) R5S2 (0.1 atmosphere).
8. Same as 7, but total concentration, 1.75 atmospheres.

TEXT FIGURES

FIG. 1. Diagram, showing relative values of top length for series 4, with 3-salt solution type I (increments of one-seventh, total concentration of 0.0061 gram-molecules per liter or 0.23 atmosphere). Lightly shaded area includes best-balanced sets of salt proportions; heavily shaded area includes poorest sets.
2. Diagram, showing relative values of root length for series 4, with 3-salt solution type I (increments of one-seventh, total concentration of 0.0061 gram-molecule per liter or 0.23 atmosphere).
3. Diagrams, showing good and poor sets of salt proportions for four plant forms.
4. Diagram, showing top-yield values for the thirty-five different sets of salt proportions, with low-medium total concentration.
5. Diagram, showing root-yield values for the thirty-five different sets of salt proportions, with low-medium total concentration.
6. Diagram, showing top-yield values for the thirty-five different sets of salt proportions, with high-medium total concentration.
7. Diagram, showing root-yield values for the thirty-five different sets of salt proportions, with high-medium total concentration.
8. Diagram, showing distribution of low, medium, and high green-weight values for series 16 and 19 combined.
9. Diagram, showing distribution of low, medium, and high water-absorption values for series 16 and 19.
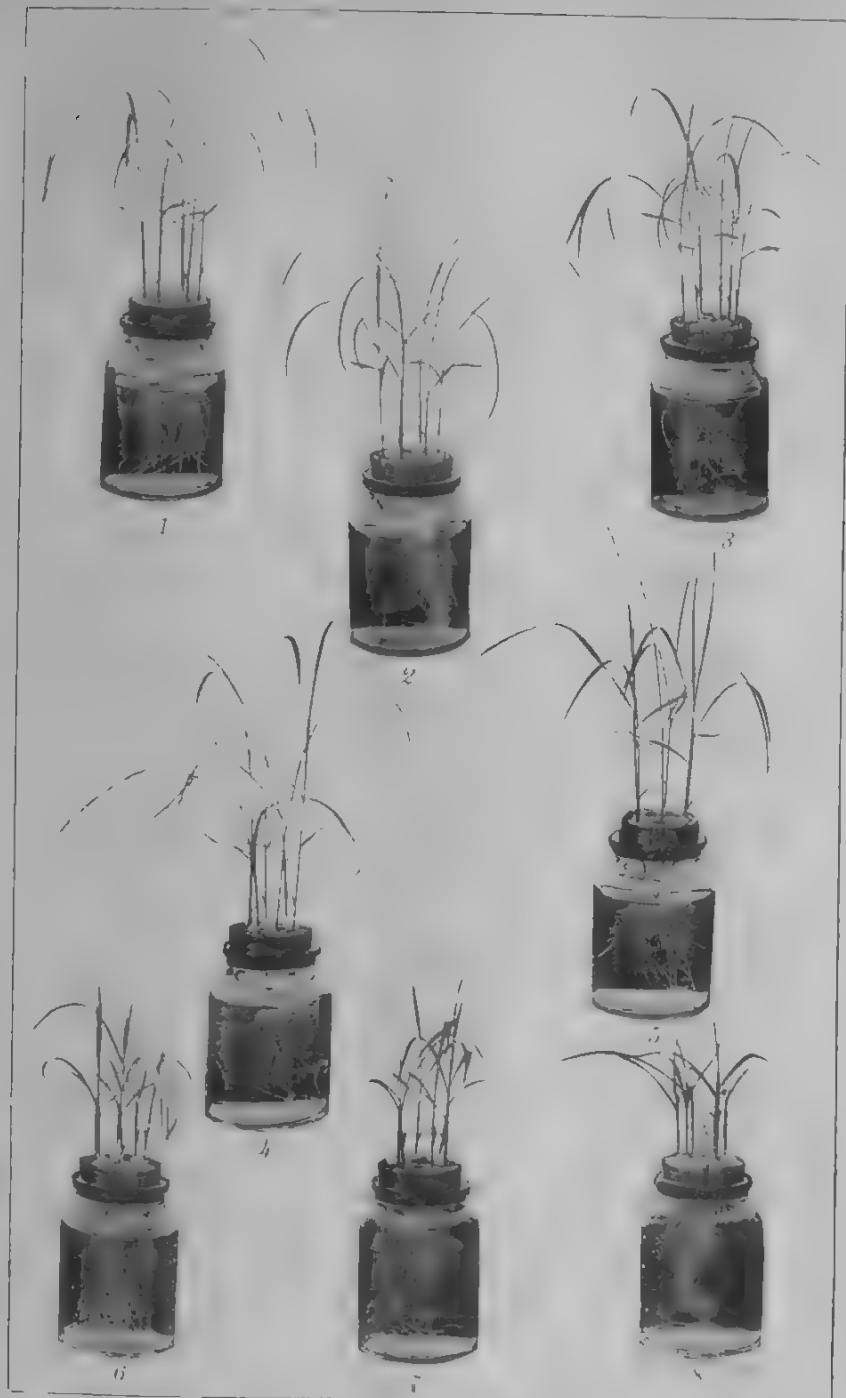
525

PLATE 1. REPRESENTATIVE CULTURES OF THE FINAL COMPARATIVE SERIES, AT
THE END OF THE CULTURE PERIOD.

HIGHER BASIDIOMYCETES FROM THE PHILIPPINES AND THEIR HOSTS, III

By O. A. REINKING

Plant Pathologist of the College of Agriculture and of the Agricultural Experiment Station, Los Baños, P. I.

The following list is a continuation of determinations of Philippine wood-destroying fungi collected on Mount Maquiling, in the vicinity of Los Baños, Laguna Province, Luzon, in Mindanao, and in Sulu as indicated in the text. The collections have been made either by me, or by my students under my direction. All identifications as herein given were made by N. Patouillard, of Neuilly-sur-Seine, France.

The species are grouped, in so far as is possible, according to the classification of Engler and Prantl, with the host and the collector under each species of fungus. The numbers refer to the College of Agriculture fungus herbarium.

AURICULARIACEAE

AURICULARIA Bulliard

AURICULARIA MESENTERICA (Dicks.) Fr.

Mount Maquiling, *Collado 129*, on decaying log.

AURICULARIA POLYTRICHA (Mont.) Sacc. (*A. purpurascens* Jungh.).

Bambusa, Jolo, *Reinking 2429*, on dead stem.

Columbia serratifolia (Cav.) DC., Mount Maquiling, *Reinking 2621*, on dead wood.

Ficus benjamina Linn., Mount Maquiling, *Divinagracia 2474*, on dead wood.

Gliricidia sepium (Jack.) Steud., Mount Maquiling, *Reinking 2619*, on dead wood.

Theobroma cacao Linn., Mount Maquiling, *Marajas 1521*, on dead branches.

AURICULARIA RUGOSISSIMA Lév.

Mindanao, Davao, Pantucan, *Reinking 2434*, on dead wood.

AURICULARIA TENUIS Lév.

Bambusa, Jolo, *Reinking 2430*, on dead stem.

Zea mays Linn., Los Baños, *Reinking 1918*, on dead leaves.

TREMELLACEAE

HETEROCHAETE Patouillard

HETEROCHAETE TENUICULA (Lév.) Pat.

Citrus, Davao, *Reinking 2291*, on dead twigs.

TREMELLA Dillenius

TREMELLA.

Mount Maquiling, *Santos 2496*, on dead wood.

THELEPHORACEAE

STEREUM Persoon

STEREUM AFFINE Lév.

Mount Maquiling, *Collado 1852*, on decaying wood.

STEREUM HIRSUTUM Fr.

Parkia javanica (Lam.) Merr. (*Parkia roxburghii* G. Don), Mount Maquiling, *Leaño 1014*, on dead wood.

STEREUM INVOLUTUM Kl.

Mount Maquiling, *Collado 1381*, on dead wood.

STEREUM LOBATUM (Kze.) Fr.

Ficus religiosa Linn., Mount Maquiling, *Pañganiban 311*, on dead wood.

Ficus, Mount Maquiling, *Collado 1363*, on dead wood.

STEREUM LOBATUM K. var. CONCOLOR Pat.

Mount Maquiling, *Collado 150, 1467*, on decaying wood.

CLAVARIACEAE

PHYSALACRIA Peck

PHYSALACRIA ORINOCENSIS Pat. et Gaett. (*Physalacria langlosii* Ellis).

Psidium guajava Linn., Mount Maquiling, *Lontoc 1022*, on dead wood.

POLYPORACEAE

FOMES Fries

FOMES APPLANATUS Pers.

Citrus, Mount Maquiling, *Pañganiban 2351*, on dead branches.

Parashorea plicata Brandis, Mount Maquiling, *Daproza 460*, on dead wood.

FOMES CALIGNOSUS Berk.

Ficus Mount Maquiling, *Collado 2347*, on dead wood.

FOMES FASTUOSUS Lév.

Parashorea plicata Brandis, Mount Maquiling, *Catalan 2350*, on dead wood.

FOMES PULLUS Mont.

Croton, Mount Maquiling, *Collado 1428*, on dead wood.
Tabernaemontana pandacaqui Poir, Mount Maquiling, *Collado 1835*, on living stem.

GANODERMA Karsten

GANODERMA APPLANATUM Pers.

Parashorea plicata Brandis, Mount Maquiling, *Daproza 460*, on dead wood.

GANODERMA AUSTRALE (Fr.) Pat.

Citrus, Mount Maquiling, *Pañganiban 2351*, on dead wood.

GANODERMA LUCIDUM (Leyn.) var **BAMBUSAE** Pat.[1]

Bambusa spinosa Roxb. (*Bambusa blumeana* Schultes), Mount Maquiling, *Reyes 2514, Nantes 522, Pañganiban 968*, on dead stem.
Bambusa vulgaris Schrad. var. *striata* (Lodd.) Gamble, Mount Maquiling, *Marquez 307*, on dead stem.

POLYPORUS Micheli

POLYPORUS ADUSTUS Fr.

Mount Maquiling, *Baybay 2527*, on dead wood.

POLYPORUS AFFINIS Nees.

Quercus sp., Mount Maquiling, *Collado 1364*, on dead wood.

POLYPORUS ANEBUS Berk. (*vulneratus* Lév. = *sanguinarius*, etc.).

Ficus benjamina Linn., Mount Maquiling, *Nantes 1015*, on dead wood.
Ficus religiosa Linn., Mount Maquiling, *Divinagracia 919*, on dead wood.

POLYPORUS BADIUS Jungh. (*Polyporus vinosus* Berk.).

Nauclea, Mount Maquiling, *Collado 114*, on decaying wood.

POLYPORUS BICOLOR Jungh.

Mount Maquiling, *Baybay 964, Pañganiban 747*, on dead wood.

---

[1] *Ganoderma lucidum* Leyn. var. *bambusae* Pat., *2514, 968, 522, 307* are forms found especially on bamboo; they are characterized by a slender stipe and a smaller pileus.

POLYPORUS DICHROUS Fr.

Eugenia calubcob C. B. Rob., Mount Maquiling, *Collado 1878*, on dead wood.

Leucaena glauca (Linn.) Benth., Mount Maquiling, *Collado 1880*, on dead wood.

Parashorea plicata Brandis, Mount Maquiling, *Collado 1484*, on dead wood.

Polyalthia, Mount Maquiling, *Collado 1477*, on dead wood.

POLYPORUS GALLOPAVONIS Berk.

Aporosa sphaeridophora Merr., Mount Maquiling, *Collado 1875*, on dead wood.

Ficus, Mount Maquiling, *Collado 1449*, on dead wood.

POLYPORUS GRAMMOCEPHALUS Berk.

Mount Maquiling, *Collado 1345, 1491, Reyes 2552*, on dead wood.

POLYPORUS HEMICAPNODES Berk.

Mount Maquiling, *Nantes 2537*, on dead wood.

POLYPORUS HIRSUTUS Pers.

Castilloa elastica Cerv., Isabela, Basilan, *Reinking 2082*, on dead log.

Celtis, Mount Maquiling, *Collado 77*, on dead wood.

Cordia myxa Linn., Mount Maquiling, *Collado 68*, on dead wood.

Croton tiglium Linn., Mount Maquiling, *Reinking 3084*, on dead wood.

Leucaena glauca (Linn.) Benth., Mount Maquiling, *Collado 1495*, on dead wood.

Macaranga tanarius (Linn.) Muell.-Arg., Mount Maquiling, *Santos 2448*, on dead wood.

Manihot glaziovii Muell.-Arg., Lanao Province, Saguiaran, *Reinking 2079*, on dead wood.

Mount Maquiling, *Collado 98*, on dead grass.

POLYPORUS LIGNOSUS Kl.

Erythrima indica Linn., Mount Maquiling, *Marquez 981*, on dead wood.

POLYPORUS MICROLOMA Lév.

Terminalia comintana (Blanco) Merr., Mount Maquiling, *Collado 1388*, on dead wood.

POLYPORUS OBTECTANS Berk.

Bambusa spinosa Roxb. (*Bambusa blumeana* Schultes), Mount Maquiling, *Reyes 1164*, on dead stem.

POLYPORUS POLYZONUS Pers.

Leucaena glauca (Linn.) Benth., Mount Maquiling, *Collado 1850*, on dead wood.

POLYPORUS RIGIDUS Lév.

Mount Maquiling, *Collado 157, 1487, 1799*, on dead wood.

POLYPORUS RUGULOSUS Lév.

Annona glabra Linn., Mount Maquiling, *Quisumbing 263*, on living trunk.

Areca catechu Linn., Mount Maquiling, *Pañganiban 2477*, on dead trunk.

Artocarpus, Mount Maquiling, *Pañganiban 387*, on living trunk.

Bambusa spinosa Roxb. (*Bambusa blumeana* Schultes), Mount Maquiling, *Cazeñas 1082, 2554*, on dead stem.

Bambusa spinosa Roxb. (*Bambusa blumeana* Schultes), Jolo, *Reinking 2147*, on dead stem.

Ficus benjamina Linn., Mount Maquiling, *Divinagracia 2472*, on dead wood.

Gliricidia sepium (Jack.) Steud., Mount Maquiling, *Nantes 974*, on dead wood.

"Malungay," Mount Maquiling, *Santos 414*, on dead wood. Mount Maquiling, *Collado 1890*, on soil.

POLYPORUS SANGUINEUS Fr.

Bambusa spinosa Roxb. (*Bambusa blumeana* Schultes), Mount Maquiling, *Pañganiban 344, 740, Baybay 2568*, on dead stems.

Livistona rotundifolia Mart., Mount Maquiling, *Collado 1895*, on dead parts.

POLYPORUS SCRUPOSUS Fr.

Mangifera indica Linn., Mount Maquiling, *Marquez 272*, on dead wood.

POLYPORUS SQUAMAEFORMIS Berk.

Mount Maquiling, *Nantes 2532*, on dead wood.

POLYPORUS SULFUREUS Fr.

Mount Maquiling, *Mendoza 2519*, on dead wood.

POLYPORUS VELLEREUS Berk.

Aleurites moluccana (Linn.) Willd., Mount Maquiling, *Collado 69*, on dead wood.

POLYPORUS VINOSUS Berk.

Ficus, Mount Maquiling, *Catalan 2347*, on dead wood.

Parashorea plicata Brandis, Mount Maquiling, *Divinagracia 2487*, on dead wood.

POLYPORUS WILLIAMSIANUS Murr.

Parashorea plicata Brandis, Mount Maquiling, *Catalan 2350*, on dead wood.

POLYPORUS XANTHOPUS Fr.

Eugenia, Mount Maquiling, *Collado 107*, on dead wood.

Psidium guajava Linn., Los Baños, college grounds, *Collado 80, 1828*, on dead wood.

CORIOLUS Quelet

CORIOLUS HIRSUTUS (Fr.) Quelet.

Mount Maquiling, *Cazeñas 1005*, on dead wood.

TRAMETES Fries

TRAMETES ASPERA (Jungh.) Bres.

Mallotus, Mount Maquiling, *Collado 1383*, on dead wood.

. *Mangifera indica* Linn., Mount Maquiling, *Hernandez 956*, on dead wood.

Parashorea plicata Brandis, Mount Maquiling, *Baybay 2582*, on dead wood.

TRAMETES MEYENII Fr. (**OBSTINATUS** Cooke).

Mount Maquiling, *Collado 1472*, on dead wood.

TRAMETES PERSOONII Mont.

Allaeanthus luzonicus F.-Vill., Mount Maquiling, *Reinking 3036*, on dead petiole.

Durio zibethinus Murr., Jolo Provincial Nursery, *Reinking 2105*, on bark of living tree.

Ficus benjamina Linn., Mount Maquiling, *Pañganiban 248*, on dead wood.

Ficus ulmifolia Miq., Mount Maquiling, *Navera 917*, on dead branches.

Rottboellia exaltata Linn., Mount Maquiling, *Reinking 183*, on dead wood.

TRAMETES SCOPULOSA Berk.

Mount Maquiling, *Cazeñas 2481, Nantes 2486*, on dead wood.

TRAMETES VELLEREUS Berk.

Alstonia macrophylla Wall., Mount Maquiling, *Collado 88*, on dead wood.

LENZITES Fries

LENZITES APPLANATA Fr.

Ficus, Mount Maquiling, *Divinagracia 2460*, on dead wood.

LENZITES PALISOTII Fr.

Mount Maquiling, *Reyes 1157*, on decaying log.

HEXAGONA Fries

HEXAGONA ALBIDA Berk.

Mount Maquiling, *Cazeñas 2502*, on dead wood.

HEXAGONA THWAITESII Berk.

Ficus nota (Blanco) Merr., Mount Maquiling, *Collado 74*, on dead wood.

FAVOLUS Fries

FAVOLUS SPATHULATUS (Jungh.) Bres.

Mount Maquiling, *Nantes 1025, Divinagracia 2536*, on dead wood.

MICROPORUS

MICROPORUS XANTHOPUS (Fr.) Pat.

Mount Maquiling, *Collado 1492*, on dead wood.

AGARICACEAE

SCHIZOPHYLLUM Fries

SCHIZOPHYLLUM COMMUNE Fr.

Acacia farnesiana (Linn.) Willd., Mount Maquiling, *Reinking 1887*, on dead wood.

Areca catechu Linn., Mount Maquiling, *Collado 1841*, on dead leaves.

Bambusa vulgaris Schrad., Mount Maquiling, *Collado 2157*, on dead stem.

Citrus, Los Baños, college grounds, *Lago 1248*, on dead leaves.

Cocos nucifera Linn., Los Baños, college grounds, *Pañganiban 712, Nantes 2475, 2476*, on dead trunk.

Gliricidia sepium (Jack.) Steud., Mount Maquiling, *Collado 1830*, on dead wood.

Macaranga tanarius (Linn.) Muell.-Arg., Los Baños, college grounds, *Santos 417*, on dead branches.

LENTINUS Fries

LENTINUS CONNATUS Berk.

Mount Maquiling, *Collado 1804*, on dead wood.

LENTINUS LEUCOCHROUS Lév.

Bauhinia, Mount Maquiling, *Collado 1881,* on decaying wood.
Koordersiodendron pinnatum Merr., Mount Maquiling, *Collado 1429,* on dead wood.
Mangifera indica Linn., Mount Maquiling, *Marquez 283,* on dead wood.
. Mount Maquiling, *Mendoza 1095,* on soil.

LENTINUS SQUARROSULUS Mont.

Leucaena glauca (Linn.) Benth., Mount Maquiling, *Collado 1823, 1877,* on dead stump.
Sapium merrillianum Pax et K. Hoffm., Mount Maquiling, *Dario 1173,* on base of living tree.

LYCOPERDACEAE

LYCOPERDON Tournefort

LYCOPERDON CEPIFORME Bull.

Mount Maquiling, *Collado 1824,* on decaying wood.

LYCOPERDON ROSEUM Zoll.[3]

Mount Maquiling, *Collado 1885,* on decaying wood; *Reyes 2556,* on dead wood.

GEASTER (Micheli) Fries

GEASTER MIRABILIS Mont.

Mount Maquiling, *Marquez 2491,* on dead wood.

NIDULARIACEAE

CYATHUS Haller

CYATHUS MONTAGNEI Tul.[4]

Bambusa, Jolo, *Reinking 2431,* on dead stem.
Citrus, Mount Maquiling, *Lago 862,* on dead stem.

CYATHUS POEPPIGI Tul. (*C. sulcatus* Kalch.).

Manihot glaziovii Muell.-Arg., Lanao, *Reinking 2087,* on dead branches.
Sesamum orientale Linn. (*Sesamum indicum* Linn.), Mount Maquiling, *Reyes 860,* on living weakened pods.

---

[3] *Lycoperdon* spp. *1885* and *2556* are most probably *Lycoperdon roseum* Zoll., but the specimens sent were too few and in too poor condition to be identified with accuracy.
[4] On number *2431,* Mr. Patouillard noted a typical example, with good fruiting bodies, of *Hypocrea citrina* var. *fungicola* Karst. He states that it was his impression that this parasite was described on *Cyathus.*

CALOSTOMATACEAE

ASTRAEUS Morgan

ASTRAEUM HYGROMETRICUS (Pers.) Morgan.[4]

Mount Maquiling, *Santos 2561,* on dead fruit.

FUNGI LISTED ACCORDING TO HOSTS

ACACIA FARNESIANA (Linn.) Willd.
 Schizophyllum commune Fr. dead wood.
ALEURITES MOLUCCANA (Linn.) Willd.
 Polyporus vellereus Berk., dead wood.
ALLAEANTHUS LUZONICUS F.-Vill.
 Trametes persoonii Mont., dead wood.
ALSTONIA MACROPHYLLA Wall.
 Trametes vellereus Berk., dead wood.
ANNONA GLABRA Linn.
 Polyporus rugulosus Lév., living trunk.
APOROSA SPHAERIDOPHORA Merr.
 Polyporus gallopavonis Berk., dead wood.
ARECA CATECHU Linn.
 Polyporus rugulosus Lév., dead trunk.
 Schizophyllum commune Fr., dead leaves.
ARTOCARPUS.
 Polyporus rugulosus Lév., living trunk.
BAMBUSA.
 Auricularia polytricha (Mont.) Sacc., dead stem.
 Auricularia tenuis Lév., dead stem.
 Cyathus montagnei Tul., dead stem.
BAMBUSA SPINOSA Roxb. (*Bambusa blumeana* Schultes).
 Ganoderma lucidum (Leyn.) var. *bambusae* Pat., dead stem.
 Polyporus obtectans Berk., dead stem.
 Polyporus rugulosus Lév., dead stem.
 Polyporus sanguineus Fr., dead stem.
BAMBUSA VULGARIS Schrad.
 Schizophyllum commune Fr., dead stem.
BAMBUSA VULGARIS Schrad. var. STRIATA (Lodd.) Gamble.
 Ganoderma lucidum (Leyn.) var. *bambusae* Pat., dead stem.
BAUHINIA.
 Lentinus leucochrous Lév., decaying wood.
CASTILLOA ELASTICA Cerv.
 Polyporus hirsutus Pers., dead log.
CELTIS.
 Polyporus hirsutus Pers., dead wood.
CITRUS.
 Cyathus montagnei Tul., dead stem.
 Fomes applanatus Pers., dead branches.
 Ganoderma australe (Fr.) Pat., dead wood.
 Heterochaete tenuicula (Lév.) Pat., dead twigs.
 Schizophyllum commune Fr., dead leaves.

[4] *Astraeus hygrometricus* (Pers.) Morgan, *2561,* was a determination from a poor specimen and consequently is questionable.

Cocos NUCIFERA Linn.
　　Schizophyllum commune Fr., dead trunk, also dead leaf.
COLUMBIA SERRATIFOLIA (Cav.) D.C.
　　Auricularia polytricha (Mont.) Sacc., dead wood.
CORDIA MYXA Linn.
　　Polyporus hirsutus Pers., dead wood.
CROTON. ·
　　Fomes pullus Mont., dead wood.
CROTON TIGLIUM Linn.
　　Polyporus hirsutus Pers., dead wood.
DURIO ZIBETHINUS Murr.
　　Trametes persoonii Mont., bark of living tree.
ERYTHRINA INDICA Linn.
　　Polyporus lignosus Kl., dead wood.
EUGENIA.
　　Polyporus xanthopus Fr.
EUGENIA CALUBCOB C. B. Rob.
　　Polyporus dichrous Fr., dead wood.
FICUS.
　　Fomes calignosus Berk., dead wood.
　　Lenzites applanatus Fr., dead wood.
　　Polyporus gallopavonis Berk., dead wood.
　　Polyporus vinosus Berk., dead wood.
　　Stereum lobatum (Kze.) Fr., dead wood.
FICUS BENJAMINA Linn.
　　Auricularia polytricha (Mont.) Sacc., dead wood.
　　Polyporus anebus Berk., dead wood.
　　Polyporus rugulosus Lév., dead wood.
　　Trametes persoonii Mont., dead wood.
FICUS NOTA (Blanco) Merr.
　　Hexagona thwaitesii Berk., dead wood.
FICUS RELIGIOSA Linn.
　　Polyporus anebus Berk., dead wood.
　　Stereum lobatum (Kze.) Fr., dead wood.
FICUS ULMIFOLIA Miq.
　　Trametes persoonii Mont., dead branches.
GLIRICIDIA SEPIUM (Jack.) Steud.
　　Auricularia polytricha (Mont.) Sacc., dead wood.
　　Polyporus rugulosus Lév., dead wood.
　　Schizophyllum commune Fr., dead wood.
KOORDERSIODENDRON PINNATUM Merr.
　　Lentinus leucochrous Lév.
LEUCAENA GLAUCA (Linn.) Benth.
　　Lentinus squarrosulus Mont., dead stump.
　　Polyporus dichrous Fr., dead wood.
　　Polyporus hirsutus Pers., dead wood.
　　Polyporus polyzonus Pers., dead wood.
LIVISTONA ROTUNDIFOLIA Mart.
　　Polyporus sanguineus Linn., dead parts.
MACARANGA TANARIUS (Linn.) Muell.-Arg.
　　Polyporus hirsutus Pers., dead wood.
　　Schizophyllum commune Fr., dead branches.

MALLOTUS.

   Trametes asper (Jungh.) Bres., dead wood.

"MALUNGAY."

   Polyporus rugulosus Lév., dead wood.

MANGIFERA INDICA Linn.

   Lentinus leucochrous Lév., dead wood.

   Polyporus scruposus Fr., dead wood.

   Trametes aspera (Jungh.) Bres., dead wood.

MANIHOT GLAZIOVII Muell.-Arg.

   Cyathus poeppigi Tul., dead branch.

   Polyporus hirsutus Pers., dead wood.

NAUCLEA.

   Polyporus badius Jungh., decaying wood.

PARASHOREA PLICATA Brandis.

   Fomes applanatus Pers., dead wood.

   Fomes fastuosus Lév., dead wood.

   Ganoderma applanatum Pers., dead wood.

   Polyporus dichrous Fr., dead wood.

   Polyporus vinosus Berk., dead wood.

   Polyporus williamsianus Murr., dead wood.

   Trametes aspera (Jungh.) Bres., dead wood.

PARKIA JAVANICA (Lam.) Merr. (*Parkia roxburghii* G. Don).

   Stereum hirsutum Fr., dead wood.

POLYALTHIA.

   Polyporus dichrous Fr., dead wood.

PSIDIUM GUAJAVA Linn.

   Physalacria orinocensis Pat. et Gaett., dead wood.

   Polyporus xanthopus Fr., dead wood.

QUERCUS.

   Polyporus affinis Nees., dead wood.

ROTTBOELLIA EXALTATA Linn.

   Trametes persoonii Mont., dead wood.

SAPIUM MERRILLIANUM Pax et K. Hoffm.

   Lentinus squarrosulus Mont., base of living tree.

SESAMUM ORIENTALE Linn. (*Sesamum indicum* Linn.).

   Cyathus poeppigi Tul., living weakened pods.

TABERNAEMONTANA PANDACAQUI. Poir.

   Fomes pullus Mont., fresh stem.

TERMINALIA COMINTANA (Blanco) Merr.

   Polyporus microloma Lév., dead wood.

THEOBROMA CACAO Linn.

   Auricularia polytricha (Mont.) Sacc., dead branches.

ZEA MAYS Linn.

   Auricularia tenuis Lév., dead leaves.

THE PHILIPPINE BUREAU OF SCIENCE

RECENT PUBLICATIONS

AN INTERPRETATION OF RUMPHIUS'S HERBARIUM AMBOINENSE

By E. D. MERRILL

Based on the collections made in Amboina by the late Charles Budd Robinson

Order No. 450. Bureau of Science Publication No. 9. Paper, 595 pages and 2 maps.

Price, $3 United States currency, postpaid.

SPECIES BLANCOANAE: A CRITICAL REVISION OF THE PHILIPPINE SPECIES OF PLANTS DESCRIBED BY BLANCO AND BY LLANOS

By E. D. MERRILL

Order No. 461. Bureau of Science Publication No. 12. Paper, 423 pages and 1 map.

Price, $2.25 United States currency, postpaid.

PHILIPPINE WATER SUPPLIES

By George W. Heise and A. S. Behrman

Order No. 460. Bureau of Science Publication No. 11. Paper, 218 pages, 19 plates, and 4 text figures.

Price, $1.75 United States currency, postpaid.

VEGETATION OF PHILIPPINE MOUNTAINS

The relation between the environment and physical types at different altitudes

By WILLIAM H. BROWN

Order No. 473. Bureau of Science Publication No, 13. Paper, 434 pages, 41 plates, 30 text figures.

Price, $2.50 United States currency, postpaid.

PLEASE GIVE ORDER NUMBER

Orders for these publications may be sent to the Business Manager, Philippine Journal of Science, Bureau of Science, Manila. P. I., or to any of the following agents:

AGENTS

THE MACMILLAN COMPANY, 64-66 Fifth Avenue, New York, U. S. A.
WM. WESLEY & SON, 28 Essex Street, Strand, London, W. C., England.
MARTINUS NIJHOFF, Lange Voorhout 9, The Hague, Holland.
KELLY & WALSH, Limited, 32 Raffles Place, Singapore, Straits Settlements.
THACKER, SPINK & CO., P. O. Box 54, Calcutta, India.
THE MARUZEN CO., Limited, 11-16 Nihonbashi, Tori-Sanchome, Tokyo, Japan.

CONTENTS